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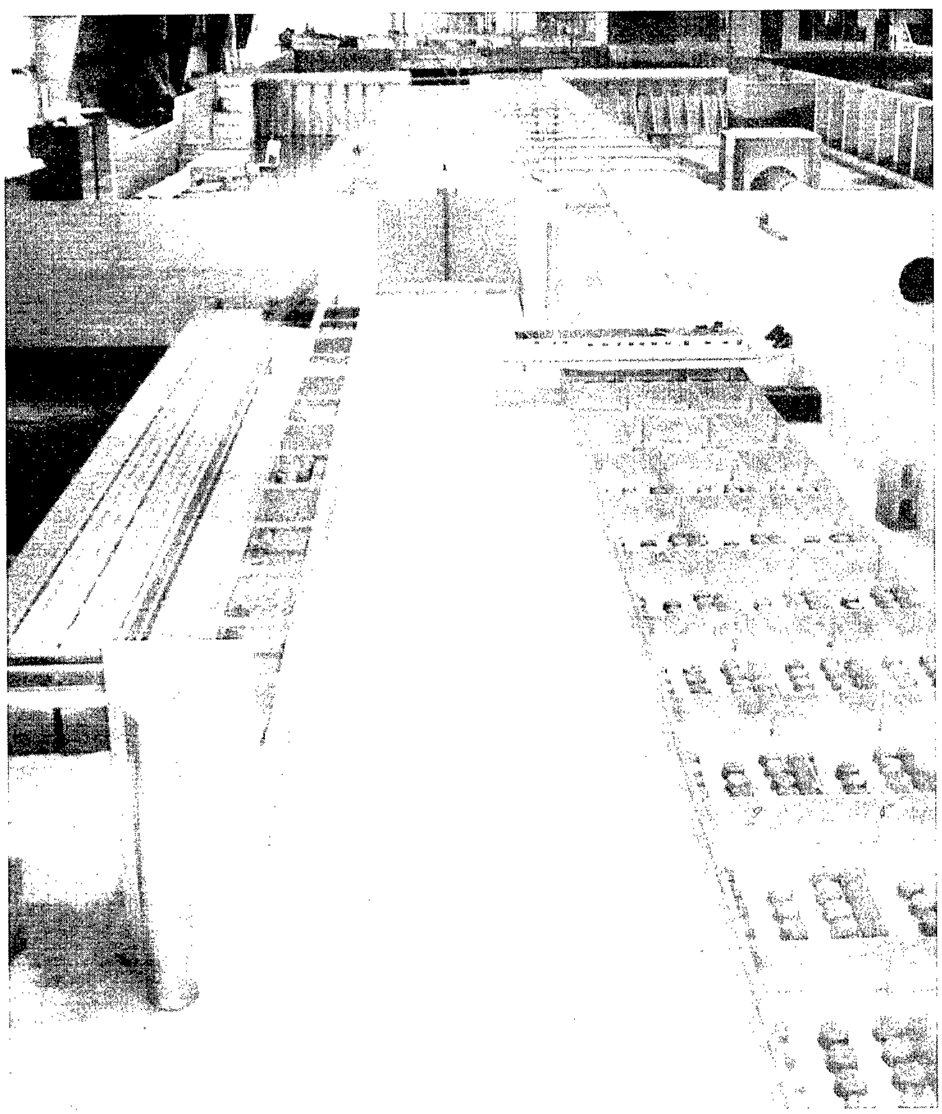
J. T. Myers Lock Filling and Emptying System, Ohio River

John E. Hite, Jr., and J. P. Crutchfield

August 2004



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Final report

Prepared for U.S. Army Engineer District, Louisville
Mazzoli Federal Building, 600 Dr. Martin Luther King Place
Louisville, KY 40202

ABSTRACT:

Navigation improvements are planned at J. T. Myers Locks and Dam on the Ohio River main stem. The project consists of a navigation dam, a 1,200-ft-long by 110-ft-wide main lock chamber adjacent to a 600-ft-long by 110-ft-wide auxiliary lock chamber. The improvements include developing a 1,200-ft-long lock chamber from the existing 600-ft-long lock chamber. The existing filling and emptying system for the 600-ft-long chamber is a bottom lateral system with the culvert located within the lock wall. This report provides the results of model investigations to determine a cost-effective and efficient lock filling and emptying system for the extended lock chamber. An innovative design for the additional filling and emptying system was evaluated. This design consisted of adding a lateral system in the extended lock chamber. The water for the additional lateral system was supplied from a through-the sill intake feeding two culverts that ran inside the chamber along the existing lock walls and over the top of the existing laterals. These culverts turned outside of the lock after passing over the existing empty culvert and then transitioned into a single culvert that fed the additional laterals in the extended chamber. The additional laterals emptied through a landside diffuser located in the lower lock approach. The initial design was considered acceptable since it filled the extended lock chamber in a reasonable time. Minor modifications were made to the design that significantly improved the chamber performance. The recommended design, type 2 design, filled the 1,381-ft-long chamber in 11.3 min and emptied the chamber in 9.6 min with the design lift of 18 ft. In addition to the development of the filling and emptying system, the effect of locking operations on tows in the approaches and the effect of the new culverts on tow entry and exit times were investigated. The original design outlet diffuser was evaluated and a separate study was performed to develop the outlet diffuser, an outlet stilling basin, and the riprap size required around the outlet.

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List of Figures

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
square feet	0.09290304	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms

Preface

The model investigation reported herein was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE) at the request of the U.S. Army Engineer District, Louisville, on 04 August 1998. The model experiments were performed during the period Aug 1998 to May 2003 by personnel of the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC) under the general supervision of Mr. Thomas W. Richardson, Director, CHL; Dr. William D. Martin, Deputy Director, CHL; Mr. Don C. Wilson, Chief, Navigation Branch, CHL, and Dr. Sandra Knight and Ms. Joan Pope, Technical Directors, CHL.

The experimental program was led by Messrs. J. P. Crutchfield and J. E. Myrick under the supervision of Dr. J. E. Hite, Jr., Leader, Locks Group. Model construction was completed by Messrs. M. A. Simmons, M. L. Bolden (retired), J. E. Gullet, and V. J. Jeffers of the Model Shop and Messrs. M. B. Brown and C. Burr and Ms. P. A. Birchett of the Carpenter Shop, Department of Public Works (DPW), ERDC, under the supervision of Mr. J. Schultz, Chief of the Model Shop, DPW, and Mr. T. M. Beard, Chief of the Carpenter Shop. Data acquisition and remote-control equipment were installed and maintained by Messrs. S. W. Guy and T. E. Nisley, Information Technology Laboratory (ITL), ERDC. Data acquisition software was developed by Dr. B. W. McCleave, ITL. The report was written by Dr. Hite and Mr. J. P. Crutchfield. Dr. R. L. Stockstill performed a peer review of the report.

During the course of the model study, Col. Robert Slockbower, Messrs. Byron McClellan, Boyd McClellan, George Herbig, David Schaaf, Brian Huston, Ken Lamkin, Jeff Bayers, Andy Lowe, Bobby Buckman, Jay Davis, Bob Kanzinger, Pete Frick, David Hawkins, and Ms. Veronica Rife of the Louisville District; Messrs. Omer Coleman and David Reed of Crounse Corp.; Mr. David K. Smith of Marathon Ashland; Mr. Samuel Dickey of ACBL; Mr. Richard Kern of Midland ENT; Mr. Barney Owens of Ingram Barge Co.; Mr. Joe Vancil of R&W Marine, and Messrs. Chuck Surprenant and Leroy Koch of the U.S. Fish and Wildlife Service visited ERDC to observe model operation, review experiment results, and discuss model results.

At the time of publication of this report Dr. James R. Houston was Director of ERDC and COL James R. Rowan, EN, was Commander and Executive Director.

1 Introduction

Background

The U.S. Army Engineer District, Louisville, is planning navigation improvements at J. T. Myers Locks and Dam on the Ohio River. These improvements include extending the existing 600-ft[1]-long by 110-ft-wide land-side chamber to accommodate a tow consisting of 15 barges, 3 wide by 5 long (each barge 35 ft wide by 195 ft long), and towboat and also modifying the approach walls for better tow entry and exit.

Prototype

The existing J. T. Myers Locks and Dam project is located on the Ohio River approximately 846 miles below its head at Pittsburgh, PA, and about 3.5 miles downstream from Uniontown, KY (Figure 1). The locks are on the Indiana side of the river. The current lock system consists of a 110-ft-wide by 1,200-ft-long main lock chamber adjacent to a 110-ft-wide by 600-ft-long-auxiliary lock chamber. The filling and emptying system for the 600-ft-long auxiliary chamber is a single-culvert bottom-lateral design with six laterals. A summary of pertinent data for the filling and emptying system is provided in Table 1. A view of the existing J. T. Myers Locks and Dam on the Ohio River is shown in Figure 2 along with a schematic of a proposed lock expansion.

Purpose and Scope

The purpose of the investigation was to identify and develop a cost effective and efficient filling and emptying system. The system was evaluated based on lock filling and emptying characteristics including fill and empty times, hawser forces on a tow in the chamber and upper approach, culvert pressures, and loss coefficients. The lock intakes and outlets were evaluated based on their efficiency and flow conditions (currents and eddies) in the vicinity of these structures. Documentation of impacts to tows moored in the upper and lower approaches were also addressed.

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page v.

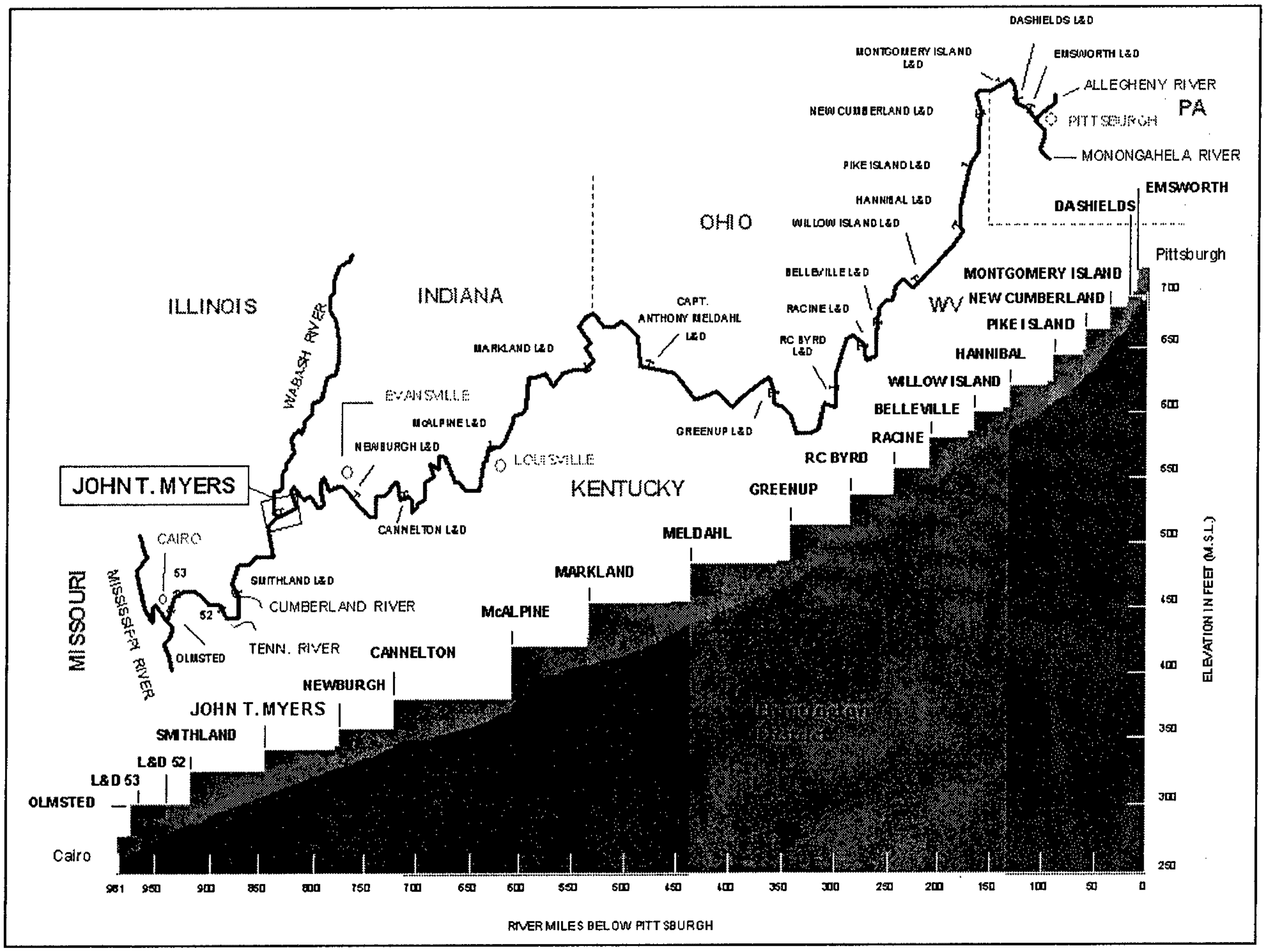


Figure 1. Location map

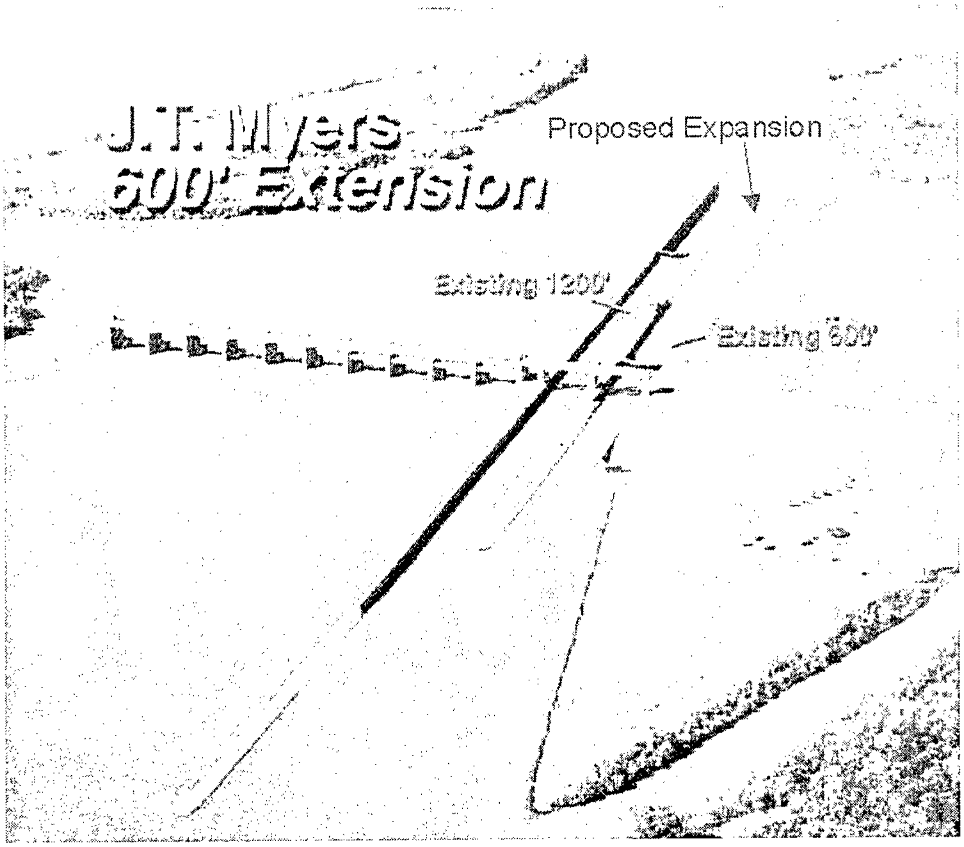


Figure 2. J. T. Myers proposed lock extension looking downstream

2 Physical Models

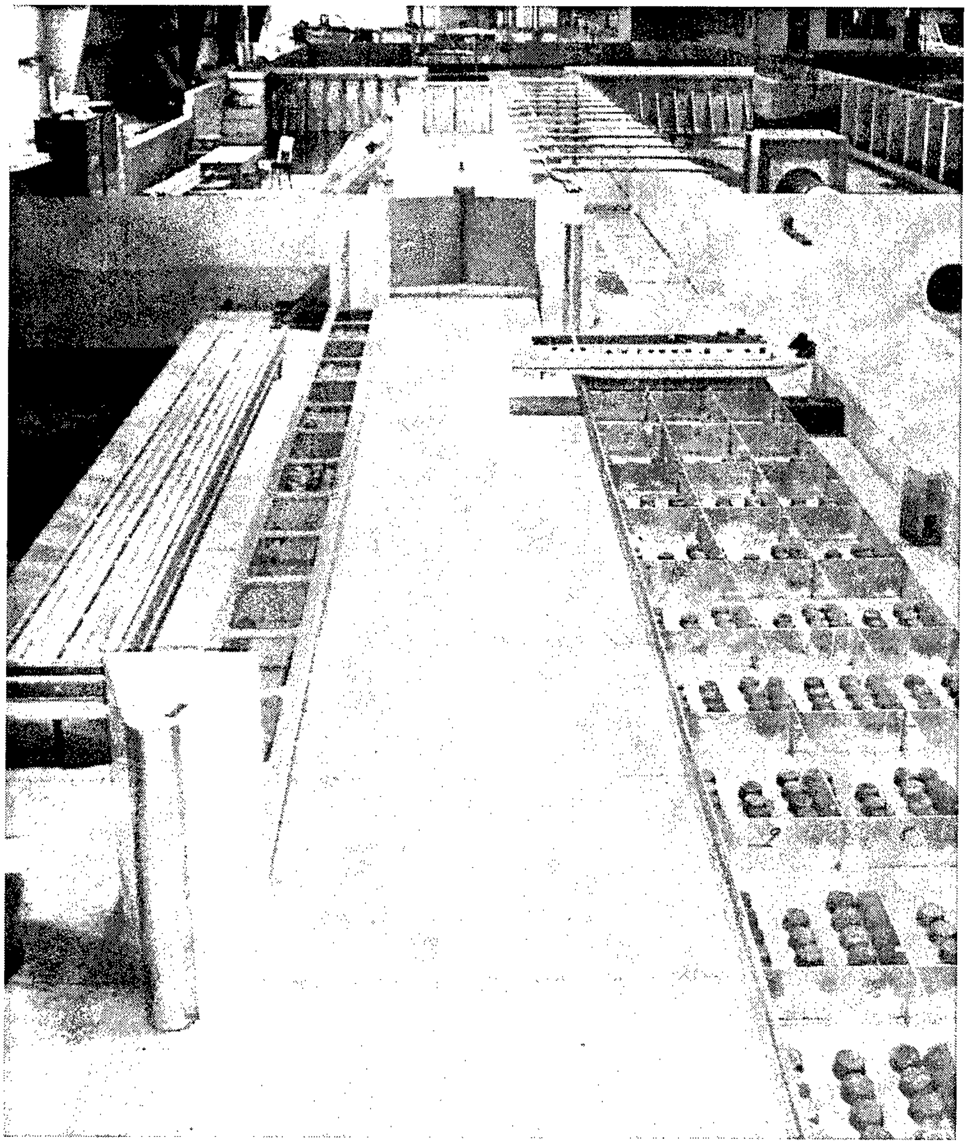
Description

The 1:25-scale J. T. Myers filling and emptying model was designed with a supplemental filling and emptying system with an additional intake and outlet. The initial design was developed in the Ohio River main stem system study. The model reproduced approximately a 1,800-ft length of the upper and lower approaches to the auxiliary lock and a 1,200-ft width of the approaches, the intakes, filling and emptying culverts and valves, laterals, and the discharge outlet. Photographs of the model are shown in Figure 3 (a-e). Figure 3a shows the lower approach looking towards the lower miter gate, and Figure 3b is a view of the upper guide walls looking upstream. Figure 3c is a close-up view of the original design through-the-sill intakes and Figure 3d shows the culverts required for the additional filling system and their location in the upper half of the chamber. Figure 3e is a side view of one of the reverse tainter valves.

The model layout is shown in Plate 1. The filling and emptying system consisted of one conventional intake located in the guard wall on the landside and a new intake located in the upper miter sill of the landside lock. Details of the filling and emptying system are shown in Plate 2. The existing intake on the landside guide wall is shown in Plate 3, and the original design through-the-sill intake is shown in Plate 4. The existing intake supplies a single14-ft-wide by 16-ft-high landside culvert that connects to a bottom lateral (six laterals) system in the upper half of the lock chamber. Details of the laterals are shown in Plates 5 and 6. The through-the-sill intake consists of two triple-box culverts with the inside dimensions of each barrel of the culvert 4.5 ft high by 8.0 ft wide. These culverts run through the sill and transition vertically and laterally to the top of the lock floor where they are located adjacent to the lock walls. The outer dimensions of each culvert were 8.5 ft high by 30 ft wide. Both these culverts run over the existing lateral field and near the midpoint of the chamber, after passing over the emptying culvert, curve outside the lock walls. Cross-section views of the culvert inside the upper half of the lock chamber are shown in Plate 7.

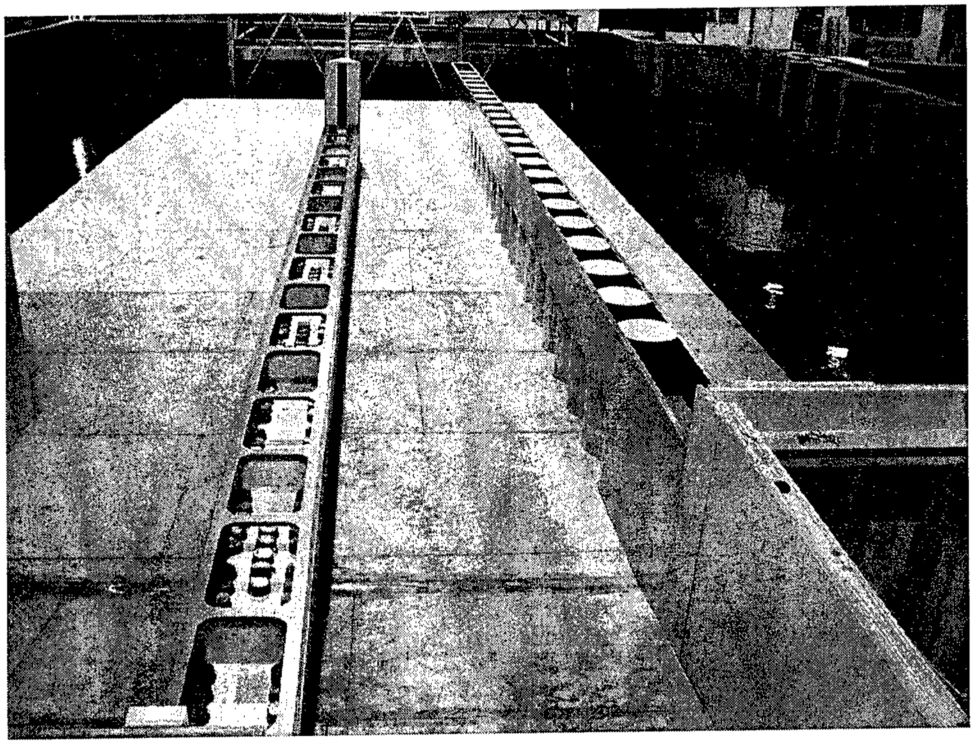
The two filling culverts, inside the chamber, transition into a single 14-ft-wide by 16-ft-high landside culvert. This single filling culvert, located outside the land wall in the lower half of the chamber, supplies a bottom lateral system identical to that in the upper half of the chamber. Details of the transition from the two triple-barrel culverts to the single culvert are shown in Plates 8 and 9. During emptying, the existing laterals in the upper half of the chamber dis-

charge back into the landside culvert, which turns and runs underneath the existing locks and discharges at an outlet bucket located outside the river wall of the main lock (Plate 2). The laterals in the lower half of the chamber discharge back into the landside culvert that connects to a landside outlet diffuser. The landside outlet diffuser was selected for the lock extension to minimize traffic delays during construction. The location of the diffuser in relation to the lock addition is shown in Plate 2 and details of the diffuser are provided in Plates 10 and 11. The diffuser was a multiported type with eight ports 7 ft high by 4.5 ft wide.



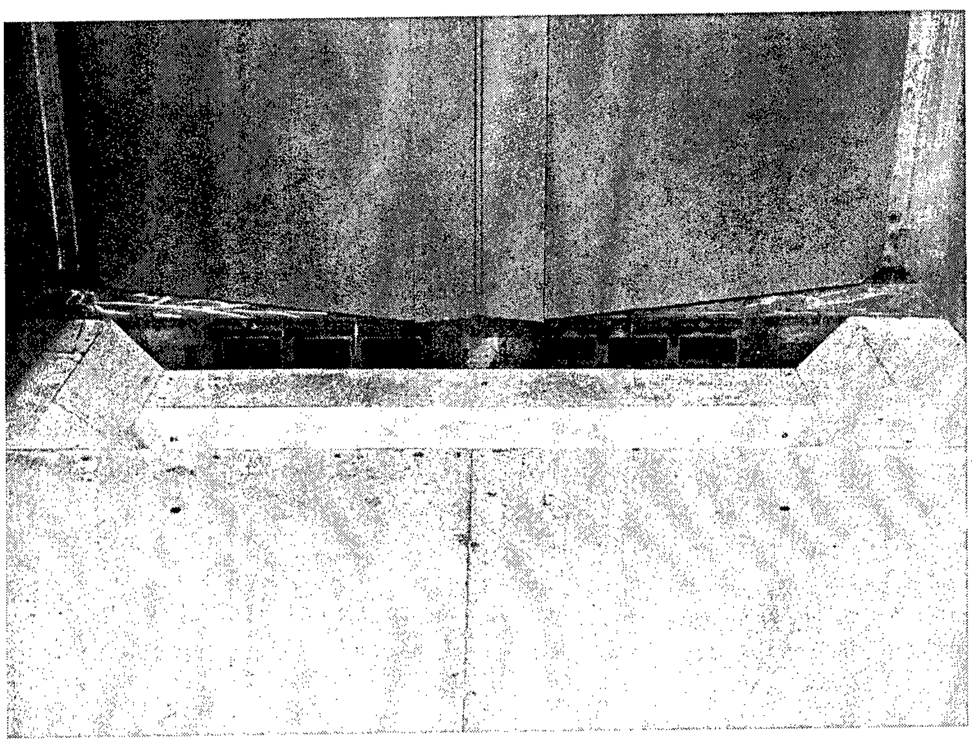
a. View of lower approach looking upstream

Figure 3. 1:25-scale filling and emptying model (Sheet 1 of 5)



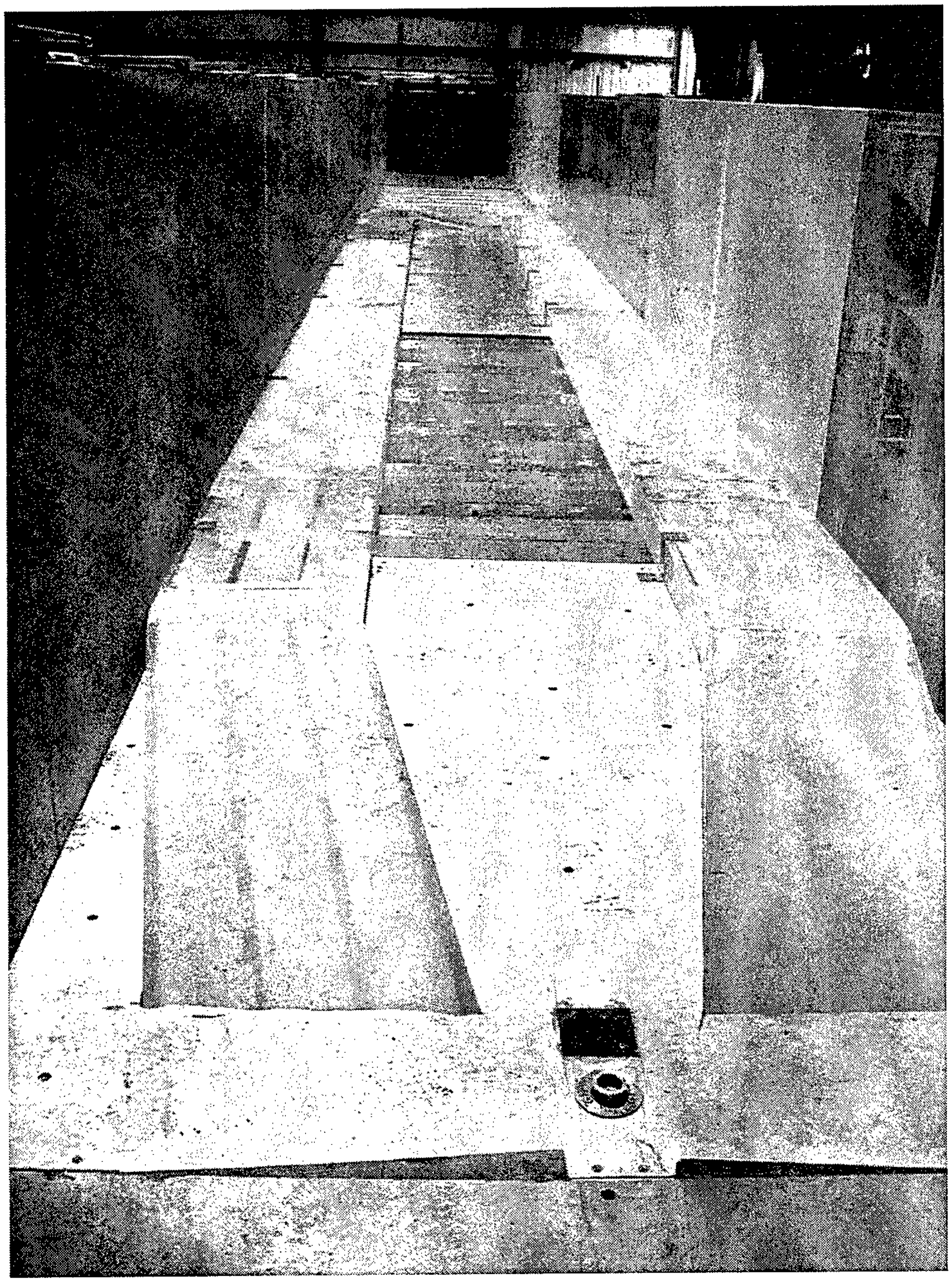
b. View of upper approach looking upstream

Figure 3. (Sheet 2 of 5)



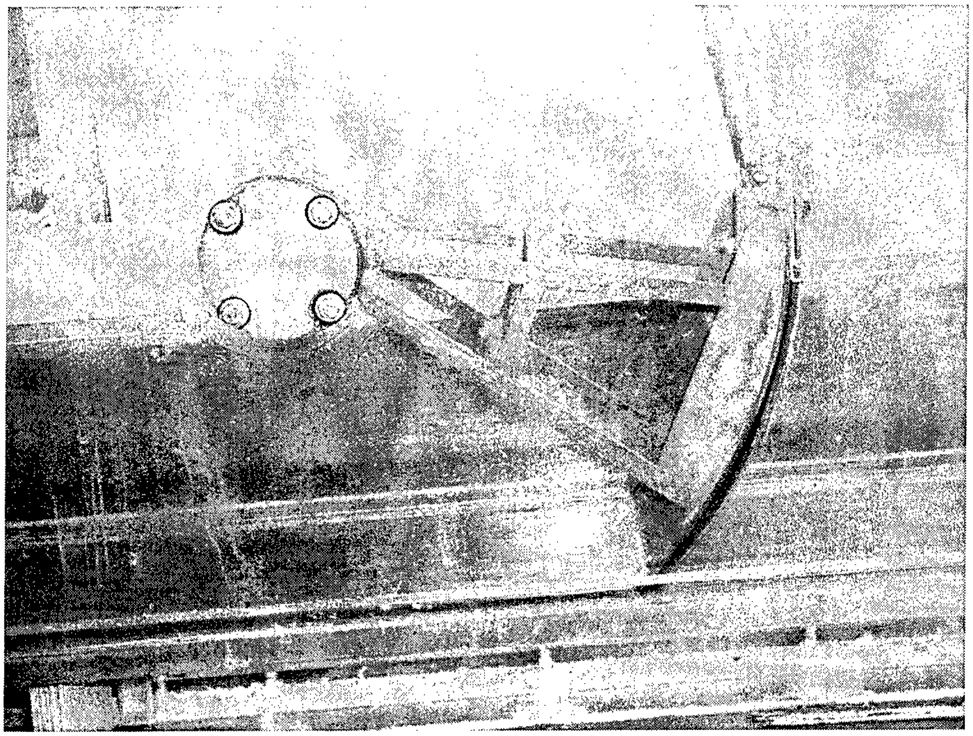
c. View of through-the-sill intake

Figure 3. (Sheet 3 of 5)



d. View of triple box culverts in upper half of chamber looking downstream

Figure 3. (Sheet 4 of 5)



e. Reverse tainter valve

Figure 3. (Sheet 5 of 5)

A 1:25-scale section model of the outlet diffuser was constructed in a separate flume from the J. T. Myers filling and emptying model since construction of the Greenup filling and emptying model had to be initiated in the lock filling and emptying facility. This model reproduced a 600-ft width and 1,500-ft length of the lower approach beginning at the emptying valve for the downstream filling and emptying system. The model included the reverse tainter valve for emptying, the lock culvert between the emptying valve and outlet diffuser, the landside outlet diffuser and portions of the lower approach topography. Results from this study are reported in Hite (in preparation).

Appurtenances and Instrumentation

Water was supplied to the model through a circulating system. The upper and lower pools were maintained at near constant elevations during the filling and emptying operations using constant head skimming weirs in the model headbay and tailbay. During a typical filling operation, excess flow was allowed to drain over the weirs at the beginning of the fill operation and minimal flow over the weir was maintained at the peak discharge thereby minimizing the drawdown in the upper reservoir. The opposite of this operation was performed during lock emptying. Upper and lower pool elevations were set to the desired level by adjusting the skimming weirs and reading piezometers placed in calm areas of the upper and lower pools. Water-surface elevations inside the chamber were determined from electronic pressure cells located in the middle and on each end of the lock chamber. Pressure cells were also used to measure instantaneous

pressures in the culvert just downstream of the filling and emptying valves. Histories of the end-to-end water-surface differential were also recorded during filling and emptying operations. Dye and confetti were used to study subsurface and surface current directions. Pressures throughout the systems were measured with piezometers (open-air manometers). Pressures obtained in this manner are considered average pressures because of the reduction in frequency response resulting from the use of nylon tubing.

An automated data acquisition and control program, Lock Control[1] was used to control valve operations and collect pressure and strain gauge data. Thirteen data channels were used, four for control of the filling and emptying valves, six for pressure data, and three for collecting strain gauge information. The data were usually collected at a sampling rate of 50 Hz. Some of the hawser force and lock filling and emptying data were collected at 10 Hz. These data were then processed using a computer program, LOCKDXF[2]. The processed data were used to determine lock filling and emptying times, longitudinal and transverse hawser forces, and pressures downstream from the filling and emptying valves.

A hawser-pull (force links) device used for measuring the longitudinal and transverse forces acting on a tow in the lock chamber during filling and emptying operations is shown in Figure 4. Three such devices were used: one measured longitudinal forces and the other two measured transverse forces on the downstream and upstream ends of the tow, respectively. These links were machined from aluminum and had SR-4 strain gauges cemented to the inner and outer edges. When the device was mounted on the tow, one end of the link was pin-connected to the tow while the other end was engaged to a fixed vertical rod. While connected to the tow, the link was free to move up and down with changes in the water surface in the lock. Any horizontal motion of the tow caused the links to deform and vary the signal, which was recorded with a personal computer using an analog-to-digital converter. The links were calibrated by inducing deflection with known weights. Instantaneous pressure and strain gauge data were recorded digitally with a personal computer.

Similitude Considerations

Kinematic similitude

Kinematic similarity can be used for modeling free-surface flows in which the viscous stresses are negligible. Kinematic similitude requires that the ratio of inertial forces ($pV^2 L^2$) to gravitational forces (pgL^3) in the model are equal to those of the prototype. Here, p is the fluid density, V is the fluid velocity, L is a characteristic length, and g is the acceleration due to gravity. This ratio is generally expressed as the Froude number, N_F.

[1] Written by Dr. Barry W. McCleave, Information Systems Development Division, Information Technology Laboratory, ERDC.
[2] Written by Dr. Richard L. Stockstill, Navigation Branch, Coastal and Hydraulics Laboratory, ERDC.

$$N_F = \frac{V}{\sqrt{gL}} \tag{1}$$

where L, the characteristic length, is usually taken as the flow depth in open-channel flow.

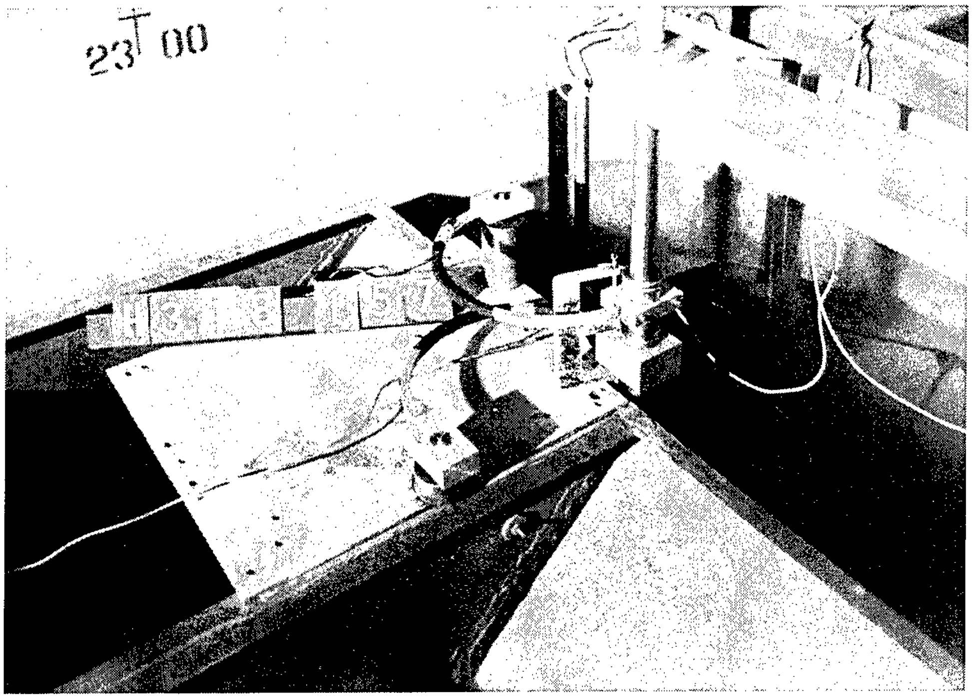


Figure 4. Hawser-pull (force links) measuring device

The Froude number can be viewed in terms of the flow characteristics. Because a surface disturbance travels at celerity of a gravity wave, $(gh)^{1/2}$, where h is the flow depth, it is seen that the Froude number describes the ratio of advection speed to the gravity wave celerity. Evaluation of the lock chamber performance primarily concerns modeling of hawser forces on moored barges during filling and emptying operations. These hawser forces are generated primarily by slopes in the lock chamber water surface. The tow's bow-to-stern water-surface differentials are the result of long period seiches or oscillations in the lock chamber. Seiching is gravity waves traveling in the longitudinal direction from the upper miter gates to the lower miter gates.

Dynamic similitude

Modeling of forces is a significant purpose of the laboratory investigation. Appropriate scaling of viscous forces requires the model be dynamically similar to the prototype. Dynamic similarity is accomplished when the ratios of the inertia forces to viscous forces (μVL) of the model and prototype are equal. Here, μ is the fluid viscosity. This ratio of inertia to viscous forces is usually expressed as the Reynolds number:

$$N_R = \frac{VL}{V} \tag{2}$$

where v is the kinematic viscosity of the fluid ($v = \mu / p$) and the pipe diameter is usually chosen as the characteristics length, L, in pressure flow analysis.

Similitude for lock models

Complete similitude in a laboratory model is attained when geometric, kinematic, and dynamic similitudes are satisfied. Physical models of hydraulic structures with both internal flow (pressure flow) and external flow (free surface) typically are scaled using kinematic (Froudian) similitude at a large enough scale so that the viscous effects in the scaled model can be neglected. More than 50 model and 10 prototype studies of lock filling and emptying systems have been investigated (Pickett and Neilson 1988). The majority of these physical model studies used a scale of 1 to 25 (model to prototype). Lock model velocities scaled using kinematic similitude (model Froude number equal to prototype Froude number) in a 1: 25-scale model have maximum Reynolds numbers at peak discharges on the order of 10^5 yet the corresponding prototype values are on the order of 10^7.

Boundary friction losses in lock culverts are empirically described using the "smooth-pipe" curve of the Darcy-Weisbach friction factor where the head loss is expressed as

$$H_f = f \frac{L}{D} \frac{V^2}{2g} \tag{3}$$

where H_f is the head loss due to boundary friction, f is the Darcy-Weisbach friction factor, L is the culvert length, and D is the culvert diameter. The Darcy-Weisbach friction factor for turbulent flow in smooth pipes is given in an implicit form (Vennard and Street 1982).

$$\frac{1}{\sqrt{f}} = 2.0 \log\left(N_R \sqrt{f}\right) - 0.8 \tag{3}$$

Because f decreases with increasing N_R, the model is hydraulically "too rough." The scaled friction losses in the model will be larger than those experienced by the prototype structure. Consequently, the scaled velocities (and discharges) in the model will be less and the scaled pressures within the culverts will be higher than those of the prototype. Low pressures were not a major concern with the J. T. Myers design; however, the lower discharges would in turn result in longer filling and emptying times in the model than the prototype will experience. Prototype filling and emptying times for similar designs will be less than those measured in a 1:25-scale lock model.

Modeling of lock filling and emptying systems is not entirely quantitative. The system is composed of pressure flow conduits and open-channel components. Further complicating matters, the flow is unsteady. Discharges (therefore N_F and N_R) vary from no flow at the beginning of an operation to peak flows within a few minutes and then return to no flow at the end of the cycle. Fortunately though, engineers now have about 50 years of experience in conducting large-scale models and subsequently studying the corresponding prototype performance. This study used a 1:25-scale Froudian model in which the viscous differences were small and could be estimated based on previously model-to-prototype comparisons. Setting the model and prototype Froude numbers equal results in the following relations between the dimensions and hydraulic quantities as shown in the following tabulation.

Characteristic	Dimension[1]	Scale Relation Model:Prototype
Length	$L_r = L$	1:25
Pressure	$P_r = L_r$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Time	$T_r = L_r^{1/2}$	1:5
Force	$F_r = L_r^3$	1:15,625
[1]Dimensions are in terms of length.		

These relations were used to transfer model data to prototype equivalents and vice versa.

Experimental Procedures

Evaluation of the various elements of the lock system was based on data obtained during typical filling and emptying operations. Performance was based primarily on hawser forces on tows in lockage, roughness of the water surface, pressures, and time required for filling and emptying. Quantification of energy loss coefficients was made using fixed-head (steady-flow) conditions with the culvert valve and/or miter gates fully opened or closed.

3 Model Experiments and Results

Type 1 Design

Tow maneuverability experiments with type 1 design

Initial experiments were performed to determine the effect on tow entry and exit performance with the filling culverts located in the upper half of the lock chamber. A tow entry speed of 1.5 ft/sec was considered an average speed for an upbound tow and was determined from data obtained at McAlpine lock during October and November 1999. The average tow exit speed determined from this data was 1.8 ft/sec.

Tow entry performance, upper pool el 342[1] and lower pool el 324. Experiments were performed with a model towboat and 15 barges (3 wide by 5 long) upbound and drafted to 9 ft. For these experiments, the culverts were removed from the upper half of the chamber. The remote controlled towboat was operated in a manner to try and simulate the average entry speed of 1.5 ft/sec. The controller settings were adjusted until a speed close to this was established. An entry speed of 1.4 ft/sec could be reproduced consistently and this was considered close enough to the representative speed 1.5 ft/sec determined from the field data.

The upstream culverts were then placed back in the chamber. The controller settings determined as previously described were then set and the experiments with the culverts were performed. The tow entry speed in the experiments was determined by placing the tow in the lower approach and recording the elapsed time between when the bow of the first barge and the end of the fourth barge crossed over the lower miter sill. The velocity was computed knowing the length of barges and the elapsed time. The average entry speed of the tow with the culverts in the chamber (type 1 design) determined in the same manner previously described was 1.5 ft/sec. These results, shown in Table 2, indicate the culverts placed inside the chamber did not impact the entry performance for this tow arrangement and pool conditions.

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[1] All elevations (el) cited herein are in feet referenced to the National Geodetic Vertical Datum. To convert feet to meters, multiply number of feet by 0.3048.

Tow exit performance, upper pool el 342 and lower pool el 324. The tow exit tests were performed by placing the downbound tow and barges in the chamber with the stern of the tow 50 ft upstream from the lower pintle, setting the towboat controls, and recording the elapsed time between when the bow of the first barge and the stern of the fourth barge crossed the lower miter sill. The tow exit average speed without the culverts in the chamber was 1.8 ft/sec. Using this same controller setting, the average exit speed of the tow with the culverts in the chamber was 1.3 ft/sec (Table 2). The additional culverts inside the chamber reduced the exit speed of the tow due to the reduction in the flow area.

Chamber performance experiments

Experiments were conducted to evaluate the lock chamber performance of the type 1 design. Hawser forces were measured with the center of a 6 long by 3 wide barge arrangement drafted to 9 ft located in the center of the lock chamber.

Filling, 18-ft lift. Chamber performance during filling was determined first with upper pool el 342.0 and a lower pool el 324.0 (18-ft lift). This was the maximum lift condition for the J. T. Myers project. Typical time-histories obtained with a valve speed of 4 min are shown in Plate 12. The maximum upstream longitudinal hawser force measured with the 4-min valve operation was 2.9 tons and occurred shortly after the valve was opened. The maximum downstream longitudinal hawser force was 8.1 tons and occurred about 3 min into the filling operation. The maximum transverse force was 2.4 tons. The filling time was 11.1 min. Typical time-histories with these same pool conditions and 5- and 8-min valve operations are shown in Plates 13 and 14.

Corps guidance (HQUSACE 1995a, b) states that acceptable lock chamber performance is achieved when the hawser forces determined from model experiments are not greater than 5 tons and the filling time is acceptable. To determine acceptable chamber performance from the model data, the average of the three maximum values for the hawser forces and filling times for the various valve operations were plotted as shown in Plate 15. The longitudinal hawser forces are generally higher than the transverse forces and are the forces that determine the time for acceptable chamber performance. The filling time that results in a downstream longitudinal hawser force of 5 tons was 11.8 min. Thus, the filling time required to achieve acceptable hawser forces of 5 tons or less was 11.8 min.

Emptying, 18-ft lift. Chamber performance with an 18-ft lift was determined next during emptying. Typical time-histories obtained with a 1-, 1.5-, 2-, 5-, and 8-min valve operations are shown in Plates 16-20. Similarly to the filling experiments, the acceptable chamber performance was determined by averaging the maximum hawser forces determined from a series of experiments for these valve operations. The average maximum hawser forces from these experiments are shown in Plate 21. The emptying time required to maintain hawser forces of 5 tons or less was 9.3 min.

Nonsynchronous valve operations. Experiments were performed with upper pool el 342 and lower pool el 324 to determine the effects of using

nonsynchronous valve operations. The goal of these experiments was to determine if a faster filling time could be achieved using different speeds for the upper and lower filling valves while keeping the maximum hawser forces below 5 tons. The results with constant speed valve operations indicated that with the 18-ft lift, a filling time of 11.8 min was required to keep the hawser forces from exceeding 5 tons. This filling time was achieved using a 5-min valve operation. Therefore, this was the target time for the nonsynchrounous valve experiments. The valve curve (valve position and time relationship) for a constant speed valve is shown in Plate 22. The chamber performance experiments with constant speed valves revealed that the water surface in the upper portion of the chamber during most of the filling operation was higher than the water surface in the lower portion of the chamber. The pronounced period of downstream longitudinal hawsers indicated higher water levels in the upper portion of the chamber.

In an effort to try and balance the water levels during filling, a faster downstream valve was tested. The first nonsynchronous valve operation was performed with a 5-min valve operation for the existing system (upstream filling valve) and a 4-min valve for the new system (downstream filling system). A plot of the typical time-histories of water surface and hawser forces measured with this operation is shown in Plate 23. The maximum upstream hawser force was 3.9 tons and occurred near 1 min into the operation. The maximum downstream hawser force was 6.7 tons and occurred near 4 min into the filling operation. The filling time was 11.3 min. The filling time was faster than the target time of 11.8 min with these valves, but the hawser forces were higher than 5 tons.

The next experiment was performed with the upper filling valve on a 6.25-min valve schedule and stopped at 80 percent open, and a 5-min valve schedule for the downstream filling valve. The logic was to stop the valves at the same time and try to reduce the water level in the upper end of the chamber. The maximum upstream hawser force was 2.9 tons and occurred at 40 sec and the maximum downstream hawser force was 4.9 tons and occurred between 4 and 5 min into the filling operation. The filling time was 13.0 min. Time-histories of data obtained with these valve operations are shown in Plate 24. The hawser forces were less than 5 tons, however the filling time was increased.

The next nonsynchronous valve operation tested was with the upper filling valve on a 6.25-min valve schedule and stopped at 80 percent open and a 3-min schedule for the downstream filling valve. The maximum upstream hawser force was 9.8 tons and occurred between 1and 2 min and the maximum downstream hawser force was 6.9 tons and occurred between 3 and 4 min into the filling operation. The filling time was 13.0 min. Time-histories of data obtained with these valve operations are shown in Plate 25. Both the filling time and hawser forces were unacceptable with this type of operation.

Another nonsynchronous valve operation was tested with the upper filling valve on a 6.25-min valve schedule and stopped at 80 percent open and a 4-min schedule for the downstream filling valve. The maximum upstream hawser force was 5.9 tons and occurred between 1and 2 min into the filling operation and the maximum downstream hawser force was 6.7 tons and occurred between 4 and 5 min into the filling operation. The filling time was 13.1 min. Time-histories of

data obtained are shown in Plate 26. Again, performance with these valve operations was unacceptable.

The fifth nonsynchronous valve operation was tested with a 5-min upper filling valve and a 3-min lower filling valve. The maximum upstream hawser force was 7.7 tons and occurred between 1and 2 min and the maximum downstream hawser force was 8.8 tons and occurred between 3 and 4 min into the filling operation. The filling time was 11.3 min. Time-histories of data obtained with these valve operations are shown in Plate 27. The filling time was improved, but the hawser forces were unacceptable.

The sixth nonsynchronous valve operation was tested with the upper filling valve on a 5-min schedule and stopped at 80 percent open and a 4-min schedule for the downstream filling valve. The maximum upstream hawser force was 4.2 tons and occurred between 1and 2 min. The maximum downstream hawser force was 6.6 tons and occurred between 4 and 5 min into the filling operation. The filling time was 12.5 min. Time-histories of data obtained with these valve operations are shown in Plate 28. The filling time and hawser forces were unacceptable with these valve operations.

Results of the experiments with the nonsynchronous valve operations indicated that no improvement was observed for the valve combinations tested over that obtained with the upstream and downstream filling valves opened using a 5-min constant speed valve.

Head loss measurements. Piezometric pressures during steady flow were measured at various locations throughout the system using piezometers located as shown in Plate 29. These measurements were used to quantify loss coefficients for various components of the system. Energy loss through each component is expressed as

$$H_{Li} = K_i \frac{V^2}{2g} \tag{4}$$

where K_i is the loss coefficient for component i, and V is the culvert velocity at the filling valve. The total head loss through the system is

$$H_L = \sum H_{Li} = \sum K_i \frac{V^2}{2g} \tag{5}$$

The filling and emptying systems (the existing system or upstream system and the new system or downstream system) were evaluated separately. The loss coefficients for the individual components determined with filling and emptying operations for both systems are shown in Table 3. The loss coefficients for the filling systems were obtained by holding a steady upper pool and discharge, closing the upper miter gates with the lower miter gates open, closing the emptying valves, and opening the filling valves. The intake loss coefficient for the

upstream filling system was determined from the upper pool to piezometer A1. The upstream culvert and valve loss coefficient was determined between piezometers A1 and A6. The upstream manifold loss coefficient was determined from piezometer A6 to the lower pool elevation. The total filling system loss coefficient for the upstream filling system was 1.92.

The loss coefficient for the intake and culvert transitions for the downstream filling system was determined from the upper pool to piezometers S5L and S5R. The loss coefficient for the upstream culvert for the downstream filling system was determined between piezometers S5L and S5R and S11L and S11R. The loss coefficient for the downstream filling system culvert transitions was determined between piezometers S11L and S11R and S12. The loss coefficient for the culvert and valve well downstream of the transition for the downstream system was determined between piezometers S12 and S13. The loss coefficient for the manifold of the downstream system was determined between piezometer S13 and the lower pool. The total filling system loss coefficient for the downstream filling system was 6.83.

The loss coefficients for the emptying systems were obtained by holding a steady upper pool and discharge, opening the upper miter gates with the lower miter gates closed, closing the filling valves, and opening the emptying valves. The loss coefficient for the manifold of the upstream emptying system was determined between the upper pool and piezometer A7. The loss coefficient for the downstream culvert, valve and outlet was determined between piezometer A7 and the lower pool. The total loss coefficient for the upstream emptying system was 3.03.

The loss coefficient for the manifold of the downstream emptying system was determined between the upper pool and piezometer S14. The loss coefficient for the downstream culvert, valve, and outlet for the downstream emptying system was determined between piezometer S14 and the lower pool. The total loss coefficient for the downstream emptying system was 2.98. The loss coefficients were similar for the emptying system, which was expected.

Another method to evaluate the efficiency of a lock system is to compute an overall lock coefficient. The lock coefficient can be expressed as

$$C_L = \frac{V}{\sqrt{2gH_L}} \tag{6}$$

Equating the head loss, H_L, in each expression shows the relation between the lock coefficient and loss coefficient

$$K = C_L^{-2} \quad \text{or} \quad C_L = K^{-0.5} \tag{7}$$

where K is the sum of each K_i. The lock coefficients computed using these loss coefficients are given in the following tabulation.

System	CL
Upstream Filling	0.72
Downstream Filling	0.38
Upstream Emptying	0.57
Downstream Emptying	0.58

This method of computing the lock coefficients does not truly represent this system since in normal operations the flow is unsteady and both systems are operating together. The individual loss coefficients do indicate which components should be modified to improve the chamber performance.

An equation typically used by the U.S. Army Corps of Engineers to compute the overall lock coefficient is:

$$C_L = \frac{2A_L\sqrt{H+d}-\sqrt{d}}{A_c\left(T-kt_v\right)\sqrt{2g}} \tag{8}$$

where

A_L = area of lock chamber, ft^2

H = initial head, ft

d = over travel, ft

A_c = area of culverts, ft^2

T = filling time, sec

k = a constant

t_v = valve opening time, sec

g = acceleration due to gravity, ft/sec^2

Refer to Davis (1989) for additional information on the development of Equation 8. The term T-k t_v is the lock filling or emptying time for the hypothetical case of instantaneous valve operation and is determined directly from the filling times associated with the various valve times. The operation times during filling with upper pool el 342 and lower pool el 324 are presented in Plate 30. The lock coefficient computed for the entire lock system with these conditions during filling was 0.63 and during emptying was 0.68. The lock coefficients for filling and emptying computed from this equation are more representative of the combined losses for the two systems. The operation times for various valve operations during emptying with a lift of 18 ft and upper pool el 342 and lower pool el 324 are shown in Plate 30.

Free tow drift tests in upper approach

Filling the lock chamber causes a localized drawdown of the upper approach in the vicinity of the intakes. The effects filling the lock chamber have on a

15-barge tow in the upper approach with the type 1 design lock were investigated using a technique known as free tow drift tests. The tow was located in the upper approach at a designated location and the lock was filled with a specified valve operation. As mentioned previously, the model was operated so that minimal drainage occurred over the constant head weir during the peak discharge for filling. This was considered the most appropriate operation to represent the actual prototype conditions. The drift of the tow during the filling operation was documented by measuring the upstream and downstream movement of the barges and the time of movement. These tests were performed for specified lifts and valve operations.

The first of these tests were performed with upper pool el 342 and lower pool el 324. The 15-barge tow was initially located unmoored as shown in Plate 31. Two-min filling valves were used for both the landside and riverside locks. The barges began to move almost immediately after the valves began opening and impacted the landside upper miter gates at 3 min and 55 sec into the filling operation. With a 5-min valve and these pool levels, the barges impacted the gates at 5 min and 10 sec into the filling operation. The results from these tests are shown in Table 4, along with the 12-ft lift condition and the type 2 design that will be discussed later in this report. The free tow drift tests indicated that the barges impacted the upper miter gates for the two lift conditions and the 2- and 5-min valve operations.

Water-surface measurements in upper approach

To further investigate the flow conditions in the upper approach during filling, water-surface measurements were obtained for two lifts (12 and 18 ft) and 2- and 5-min valves at the locations shown in Plate 32. Measurements obtained with upper pool el 342 and lower pool el 324 and a 2-min valve are provided in Table 5 and plotted in Plate 33. The water-surface dropped a maximum of 0.5 ft below the upper pool between 1 and 2 min into the filling operation. The water level at sta 1+25 US began falling between 0 and 50 sec into the operation and caused the barge movement observed in the free tow drift tests.

The longitudinal hawser forces on a 3 by 5 barge arrangement moored in the upper approach as shown in Plate 32 were estimated from the water-surface elevation measurements. The water-surface slope between sta's 10+08 US and 1+25 US was determined from the difference in the elevations measured during the filling operation. These slopes were determined for the times when the water-surface elevations were measured as shown in Table 5. Neglecting the forces due to drag and inertia, assuming the barges act as a single flexible (conforms to water surface) vessel, and neglecting the effect of the vessel blockage area of the approach channel, the force required to hold the vessel in place is a function of the water-surface slope only. Using standard barge dimensions of 195 ft by 35 ft with a 9-ft draft, the longitudinal hawser force computed at 100 sec for a slope of 0.00057 ft/ft was 16.3 tons (Table 5) in a downstream direction. This was the maximum determined for these pool elevations and 2-min valve. The forces fluctuate during the filling operation and eventually reduce to minimal values when the water-surface levels. This method of computing hawser forces is not

entirely quantitative, but is considered an appropriate technique to compare different operating conditions or designs.

The water-surface elevations and the computed longitudinal hawser forces for the 5-min valve and 18-ft lift are also shown in Table 5. Plots of the water-surface elevation are shown in Plate 33. The maximum decrease in water level below the upper pool with the 5-min valves was 0.2 ft which gives a computed longitudinal hawser force of 6.5 tons. With the 2-min valve, the maximum longitudinal hawser force was 16.3 tons and with the 5-min valves the maximum computed hawser force was 6.5 tons.

The water-surface measurements were also obtained with a 12-ft lift (upper pool el of 342 and lower pool el of 330). Table 6 lists the water-surface elevations measured and the computed longitudinal hawser forces for filling valve times of 2 and 5 min. Plots of the water surface with the 12-ft lift and valve operations of 2 and 5 min are shown in Plate 34. The measured slopes with the 2-min valve are associated with a maximum longitudinal hawser force of 9.8 tons and with the 5-min valve times, the maximum computed hawser force was 6.5 tons.

A plot of the computed hawser forces for the two lift conditions is shown in Plate 35. The maximum forces recorded with the 2-min valves occurred at 100 sec into the filling operation. With the 5-min valve, the maximum hawser force was 6.5 tons and was determined for both lift conditions.

Free tow drift tests in lower approach

Free tow drift tests were conducted in the lower approach to observe movement of a 3 by 5 barge arrangement initially located as shown in Plate 36. The tests were performed with the 12- and 18-ft lifts and 2- and 5-min valve speeds. Only the landside lock was operated for these tests. The concern was that the discharge from the landside culvert could cause adverse navigation conditions in the lower approach. The results from the free tow tests in the lower approach are shown in Table 7. No rapid or excessive movement of the barges was observed. The maximum distance the barges moved downstream from their initial position was 55 ft and occurred with the 18-ft lift and 5-min valve.

Water-surface measurements in lower approach

Water-surface elevations were measured 55 ft riverward from the landside approach wall to the landside lock at distances of 102.5, 475, and 847.5 ft from the lower landside pintle. These measurements were obtained to help evaluate conditions in the lower approach during emptying operations. The water-surface elevations measured with an upper pool el of 342, a lower pool el of 324 and 2- and 5- min valve operations are listed in Table 8. Plots of the water-surface elevation during these tests are shown in Plate 37. Table 9 and Plate 38 provide the water-surface elevations and plots for an upper pool el of 342 and a lower pool el of 330 and valve speeds of 2 and 5 min. The water-surface measurements indicated that during the emptying operation, the water surface was generally higher

at the middle measuring location (sta 19+45, 475 ft downstream from the lower pintle) than the upstream and downstream measuring locations. The slope in the water surface between the measuring stations was small which supports the minimal movement observed during the free tow drift tests. Since the water-surface slopes were small, the hawser forces computed using the technique described for the upper approach would also be small.

Additional chamber performance experiments

Filling, 22- and 30-ft lifts. Additional chamber performance experiments were conducted for various upper and lower pool elevations to further evaluate the type 1 design. These conditions evaluated were not representative of the J. T. Myers project and were performed to gather additional data for use in developing lock designs for other projects on the Ohio River main stem. Average maximum hawser forces measured with upper pool el 345 and lower pool el 323 (22-ft lift) are shown in Plate 39. The filling time required to maintain hawser forces of 5 tons or less with the 22-ft lift was 14.7 min. Experiments were also performed with a 30-ft lift and lower pool el 323. Results of the hawser measurements shown in Plate 39 reveal that a filling time required to maintain hawser forces of 5 tons or less was 18.5 min.

Emptying, 22- and 30-ft lifts. Emptying experiments with a 22-ft lift (upper pool el 345 and lower pool el 323) indicated that during the under-empty portion of the operation, the barges on one side of the chamber made contact with the top of the culverts. A plot of the typical time-histories with an 8-min valve (Plate 40) show that both the upstream and downstream left transverse hawser forces rapidly increase just after the chamber water surface reached the lower pool elevation. The bottom of the barges in the upper half of the chamber probably came in contact with the culvert causing the increased forces. The average maximum hawser forces determined for the 22- and 30-ft lift (Plate 41) show that the left transverse forces exceeded 5 tons for both lifts and all valve operations tested. Chamber performance during emptying was not acceptable with lower pool el 323. The transverse hawser forces measured during emptying experiments with a 22-ft lift and lower pool el 324 (Plate 41) were less than 5 tons. This demonstrated that the submergence over the culverts was significant for chamber performance and that barges with a 9-ft draft require at least a 2.5-ft clearance from the bottom of the barge to the top of the culvert.

Summary of type 1 design performance

The chamber performance experiments indicated that permissible filling time with the type 1 design and the maximum lift of 18 ft was 11.8 min. The permissible emptying time with an 18-ft lift was 9.3 min. These numbers compare favorably with existing guidance for side port systems at these lifts. Observations of the free tow drift tests and water-surface elevations indicated flow conditions in the upper approach were satisfactory when filling both lock chambers simultaneously with 5-min valves. Much higher hawser forces were computed with a 2-min valve operation. Flow conditions in the lower approach were also satisfactory based on the free tow drift tests and the water-surface elevations.

Type 2 Design

Modifications were made to the type 1 design in an effort to distribute the flow more evenly in the chamber during filling operations and to reduce the filling time. The modifications to the intake are shown in Plates 42 and 43. The culvert height was increased from 4.5 ft to 5.5 ft, while the width remained the same. This increased the total cross-sectional area of the additional culverts from 216 sq ft to 264 sq ft. At the face of the intake, the bottom of the culvert remained the same, el 297.5, and the top was raised 1 ft to el 303. The top of the culvert was lowered 1 ft at sta 3+05 DS and remained at that elevation to the transition area. A 2 ft-radius was placed on the top and sides of the intake entrance, and a 0.75-ft radius was placed on the inner walls between the culvert barrels as shown in Plate 43. The approach to the intake was modified as shown in Plates 42 and 43 to help streamline the flow into the intake and reduce entrance losses. The transition from the two culverts to one was modified as shown in Plate 44 to accommodate the larger culvert. The modifications to the intake, transition from intake to culvert, culvert, and culvert transition were designated the type 2 design.

Head loss measurements with type 2 design

The loss coefficients for the individual components of the type 2 design filling system were determined in the same manner as with the type 1 design described previously. The same piezometer layout as shown in Plate 29 was used. The loss coefficient for the intake and culvert transitions for the downstream filling system was determined from the upper pool to piezometers S5L and S5R. The loss coefficient for the upstream culvert for the downstream filling system was determined between piezometers S5L and S5R and S11L and S11R. The loss coefficient for the downstream filling system culvert transitions was determined between piezometers S11L and S11R and S12. The loss coefficient for the culvert and valve well downstream of the transition for the downstream system was determined between piezometers S12 and S13. The loss coefficient for the manifold of the downstream system was determined between piezometer S13 and the lower pool. The individual loss coefficients are shown in Table 10 and the total filling system loss coefficient for the downstream filling system was 3.74. This compares to a total loss coefficient of 6.83 with the type 1 design filling system.

The head loss through the intake and culvert transitions were reduced significantly with the type 2 design and the increased cross-sectional area in the culverts helped reduce the friction losses in the culverts. These reduced loss coefficients indicated the type 2 filling system was more efficient than the type 1 design filling system.

Filling with type 2 design, 18-, 17-, 16-, and 12-ft lifts

Chamber performance was evaluated with lifts of 18, 17, 16, and 12 ft. An 18-ft lift is the maximum lift at J. T. Myers.

The first experiments were conducted with upper pool el 342 and lower pool el 324 (18-ft lift). Typical time-histories obtained with a valve speed of 4 min are shown in Plate 45. The averages of the maximum values for the hawser forces and filling times for three tests with each of the various valve operations were determined and are plotted in Plate 46. The longitudinal hawser forces are generally higher than the transverse forces and were the forces that determined the time for acceptable performance. The filling time that results in a downstream longitudinal hawser force of 5 tons with an 18-ft lift was 9.8 min. Thus, the filling time required to achieve acceptable hawser forces of 5 tons or less with an 18-ft lift was 9.8 min. This was 2.0 min faster than the type 1 design.

The experiments with the 17-ft lift were conducted with upper pool el 342 and lower pool el 325. The averages of the maximum values for the hawser forces and filling times are plotted in Plate 46. The filling time that results in a downstream longitudinal hawser force of 5 tons with the 17-ft lift was 9.7 min. The experiments with the 16-ft lift were conducted with upper pool el 342 and lower pool el 326. As shown in Plate 46, the filling time required to maintain hawser forces of 5 tons or less was 9.2 min. The experiments with the 12-ft lift were conducted with upper pool el 342 and lower pool el 330. The averages of the maximum values for the hawser forces and filling times are also shown in Plate 46. The filling time that results in a downstream longitudinal hawser force of 5 tons with the 12-ft lift was 7.4 min.

Free tow drift tests in upper approach with type 2 design

Free tow drift tests were performed with the type 2 design to help evaluate the flow conditions in the upper approach. The tow was located in the upper approach in the same manner as the experiments performed with the type 1 design (Plate 31). The first tests were performed with upper pool el 342 and lower pool el 324. Two-min filling valves were used for both the landside and riverside locks. The barges began to move almost immediately after the valves began opening and impacted the landside upper miter gates at 3 min and 25 sec into the filling operation. With a 5-min valve and these pool levels, the barges impacted the gates at 5 min into the filling operation. The results are provided in Table 4 along with the results obtained from the type 1 design. The barge impact times for the 2- and 5-min valve operations with a 12-ft lift are also shown in Table 4. The free tow drift tests indicated that the barges impacted the upper miter gates for the two lift conditions and the 2- and 5-min valve operations.

The time to impact was slightly less with the type 2 design because the intake was more efficient. A more efficient intake means more discharge into the intake, and more discharge would cause more drawdown in the upper approach. These results show that if a tow is in the upper approach during lock filling it should be moored securely.

Water-surface measurements in upper approach with type 2 design

Water-surface measurements were obtained for the 18-ft lift and 2- and 5-min valves at the locations shown in Plate 32. These measurements were

obtained while filling both locks at the same time and also filling the landside lock only. The measurements obtained with upper pool el 342 and lower pool el 324 and 2-min valves for both locks filling are provided in Table 11. The water surface dropped a maximum of 1.0 ft below the upper pool. The maximum water-surface differential between the upstream and downstream measuring locations was 0.3 ft and was recorded at 100 sec into filling. This differential was less than observed with the same conditions and the type 1 design (see Table 5), although the maximum water-surface drop was larger with the type 2 design. With the type 2 design, more flow was drawn into the sill intake than with the type 1 design. This caused more drawdown in the upper approach and resulted in similar water-surface levels between the measuring stations. Even though the maximum drawdown was more with the type 2 design due to the increased flow into the intakes, the water-surface differential between the measuring locations was less. Evidently, the drawdown was more local with the type 1 design.

The longitudinal hawser forces on a 3 by 5 barge arrangement moored in the upper approach as shown in Plate 31 were estimated from the water-surface elevation measurements. Since the water-surface differential was less with the type 2 design, the computed longitudinal hawser forces were less. The longitudinal hawser force computed at 100 sec for a slope of 0.00034 ft/ft was 9.8 tons (Table 11) in a downstream direction. This was the maximum hawser force determined for these pool elevations and 2-min valve.

Table 11 also provides the measured water-surface elevations and computed longitudinal hawser forces for the 5-min valve operations, an 18-ft lift and both locks filling. The maximum longitudinal hawser force computed was 6.5 tons between 150 and 250 sec into filling.

The water-surface elevations and computed hawser forces for the 18-ft lift and 2- and 5-min valve operations with only the landside lock filling are listed in Table 12. The maximum drop in water surface below the upper pool observed was 0.2 ft. The maximum water-surface differential determined between the measuring locations was 0.1 ft and the maximum longitudinal hawser force computed for these conditions was 3.3 tons.

Hawser-force measurements in upper approach with type 2 design

The hawser forces were measured in the upper approach with the barges moored as shown in Plate 31. The hawser force links device used to determine the forces inside the chamber was used for the measurements. Both the longitudinal and transverse forces were measured during selected valve operations for lifts of 18 and 12 ft and with both locks filling at the same time and only the landside lock filling.

Both locks filling with 2-, 4- and 5-min valves and 18-ft lift. Table 13 provides the hawser force measurements obtained with an 18-ft lift and 2-, 4-, and 5-min valve operations for both locks filling. The maximum downstream longitudinal hawser force measured occurred with the 2-min valve operation and was 11.4 tons. Typical time-histories obtained with the 2-min valve operations are shown in Plate 47. The maximum downstream force with 2-min valve operations

occurred 40 sec after the filling operation started. This time corresponds to the time when the higher water-surface differentials started to occur. The upstream and downstream transverse hawser forces were less than or equal to 1.5 tons for all valve operations tested.

Both locks filling with 2-, 4- and 5-min valves and 12-ft lift. Hawser force measurements in the upper approach were also obtained with a 12-ft lift and 2-, 4-, and 5- min valve operations for both locks filling. These results are listed in Table 14. The maximum downstream longitudinal hawser force measured occurred with the 2-min valve operation and was 9.6 tons. Typical time-histories of the hawser forces obtained with the 2-min valve operation are shown in Plate 48. The upstream and downstream transverse hawser forces were all less than or equal to 1.5 tons for the three valve operations tested.

Landside lock filling with 2-, 4- and 8-min valves and 18-ft lift. Experiments were conducted to determine the hawser forces on a 3 by 5 barge arrangement moored in the upper approach as shown in Plate 31 with only the landside lock filling. The results from the experiments with the 18-ft lift are provided in Table 15. The maximum downstream longitudinal hawser force measured occurred with the 2-min valve operation and was 7.4 tons. Typical time-histories obtained with the 2-min valve operation are shown in Plate 49. The hawser forces were lower than those measured with both locks filling at the same time.

Landside lock filling with 2-, 4- and 8-min valves and 12-ft lift. The maximum hawser force measured with a 12-ft lift and 2-, 4-, and 5- min valve operations with only the landside lock filling are listed in Table 16. The maximum downstream longitudinal hawser force measured occurred with the 2-min valve operation and was 5.6 tons. Typical time- histories obtained with the 2-min valve operation are shown in Plate 50. These hawser forces were less than those measured with the 12-ft lift for both locks filling.

The maximum longitudinal hawser forces measured in the upper approach with the 18- and 12-ft lifts, 2- and 4-min valve operations for both locks filling and with only the landside lock filling are shown in graphical form in Plate 51. The downstream forces are larger than the upstream. The upstream forces were not affected significantly by the lift or valve operation. The dominant wave form observed in the time-history data was the movement of the gravity wave in the upper approach. The wave appeared to travel back and forth between the upper miter gate and the end of the middle floating guard wall. As the wave reflected near the end of the floating wall, the water surface raised slightly and traveled back downstream causing the reduction in the magnitude of the downstream longitudinal hawser force seen in the time-history data in Plates 47-50.

Comparison of hawser forces in upper approach. A comparison was made of the longitudinal hawser forces computed from the water-surface measurements in the upper approach and the hawser forces measured using the force links device. The comparison for both locks filling shown in Plate 52 indicates with the 2-min valves the computed force underestimated the maximum force and with the 5-min valves, the computed force overestimated the maximum force. The computed forces were determined from water-surface measurements obtained by recording piezometer readings at the measurement locations on

video. A time-history of the water surface at 50-sec intervals was then constructed from the recording. The estimated error converted to prototype from these water-surface measurements was approximately 0.1 ft. This relates to a computed hawser force of 3.3 tons. A more sophisticated water-surface measuring device would be necessary to improve the method employed to compute the hawser forces.

Lower approach modifications

Additional design details were furnished by the Louisville District for the landside discharge area and the lower approach topography. The model was modified to include these details. Plates 53 and 54 provide details of the modified lower approach topography and discharge area. These modifications were designated the type 2 lower approach. Additional experiments were conducted with these modifications to evaluate the conditions in the lower approach during lock emptying operations with the landside diffuser.

Free tow drift tests with type 2 lower approach. Three tow configurations were evaluated with free tow drift tests. One configuration was located as shown in Plate 36 with the head of the tow on the landside wall 102.5 ft downstream from the lower pintle of the landside lock. The other two configurations were located as shown in Plate 55 with the head of the tow on the landside wall 296.0 ft downstream from the lower pintle of the landside lock and at the same location on the riverside wall. The drift tests were conducted with 18- and 12-ft lifts and 1- and 2-min emptying valve operations. The results are provided in Table 17 and indicate the distance the tow moved downstream was small with slightly more movement observed when the tow was initially located on the riverside wall. The distance the barges move downstream was less than observed with the type 1 design indicating the flow from the landside diffuser was more uniformly distributed in the lower approach with the type 2 design outlet. These tests indicted the flow conditions in the lower approach were satisfactory for a tow located in this area with the landside diffuser emptying with 1- and 2-min valve operations.

Water-surface measurements with type 2 lower approach. Water-surface elevations were measured 55 ft riverward from the landside approach wall to the landside lock at distances of 102.5, 475, and 847.5 ft from the lower landside pintle. These measurements were obtained to help evaluate conditions in the lower approach during emptying operations with the modified outlet area. The water-surface elevations measured with upper pool el 342, lower pool el 324 and 1- and 2- min valve operations are listed in Table 18. Similar data for these valve operations with upper pool el 342 and lower pool el 330 are listed in Table 19. The water-surface measurements show that during the emptying operation the water surface was generally higher at the middle measuring location (sta 19+45, 475 ft downstream from the lower pintle) than the upstream and downstream measuring locations. The slope in the water surface between the measuring stations was small, which supports the minimal movement observed during the free tow drift tests. Since the water-surface slopes were small, the hawser forces would also be small and were not large enough to install the force links device. The maximum rise above the lower pool elevation was 0.2 ft and occurred with

the 18-ft lift for both valve operations. The maximum rise above the lower pool measured with the 12-ft lift was 0.1 ft and was also observed for both valve operations.

Velocities with type 2 lower approach

Velocities were measured at selected locations in the lower approach to help design the riprap protection in the vicinity of the outlet area. The measurements were made with upper pool el 342 and lower pool el 342 using the technique described for the head loss measurements during emptying. The chamber water level was maintained at el 342 by opening the upper miter gates with the upper filling valves closed and the emptying valves open. This provided the maximum velocities that could occur during an emptying operation. The velocity measurements obtained with the 18-ft lift are shown in Plate 56. The highest velocity measured was 10.1 ft /sec in the middle of the apron at the diffuser outlet. The dimensions of the apron were 20 ft wide by 84.5 ft long with the basin invert at el 286. Since this area was subjected to the jet flow discharging from the outlet diffuser during emptying, a hardened type of scour protection is recommended. The flow in this area was highly turbulent as seen by the wide range in the velocity magnitudes and directions in Plate 56. The velocity measurements were obtained approximately 1 ft off the bottom. Due to the configuration of the model (the model cutoff wall just upstream from the diffuser), a concentrated eddy formed on the upstream side of the diffuser from the jets discharging from the upstream ports. The jets discharging from the middle of the diffuser were directed upward and outward at the end of the apron with some of the flow contributing to the eddy on the upstream side and the remaining flow spreading out in a downstream direction. High velocity flow occurred near the water surface at the top of the landside bank line. A velocity of 8.6 ft/sec was measured near the top bank approximately 400 ft downstream from the diffuser. A velocity of 5.5 ft/sec was measured near the top bank 800 ft downstream from the diffuser. The velocity of the flow along the bottom at the toe of the landside bank was low (1 to 2 ft/sec).

Summary type 2 design chamber performance

The performance of the type 2 design was an improvement over the type 1 design. The filling times were faster and the flow into the chamber during filling was more evenly distributed. The lock coefficient determined from the steady-state experiments was 0.52 for the downstream filling system compared to 0.38 determined for the type 1 design. The overall lock coefficient determined for the type 2 design from Equation 8 described previously was 0.70 (compared to 0.63 for the type 1 design). This was determined from the operation curve shown in Plate 57 for the 18-ft lift. This coefficient compares favorably with existing 1,200-ft-long by 110-ft-wide Corps locks.

Extended Chamber Experiments

Chamber performance experiments were conducted next with the lock chamber extended another 61 ft downstream. The lower pintle was moved from sta 14+70 to sta 15+31. This additional length may be required to accommodate some of the construction tasks. The experiments were performed with the center of a 3 by 6 barge group drafted to 9 ft at two different locations. The two stations were 8+10 and 8+40.5. Sta 8+10 was the center of the chamber when the length of the chamber was 1,320 ft and sta 8+40.5 was the center of the extended chamber. The two locations were evaluated to determine the effect of barge location.

Center of barges at sta 8+10

Chamber performance was determined with upper pool el 342.0 and lower pool el 324.0 (18-ft lift). The average maximum hawser forces determined for these conditions during filling are shown in Plate 58 along with the results for the barges centered at sta 8+40.5. The longitudinal hawser forces were higher than the transverse forces and were the forces that determined the time for acceptable performance. The filling time that resulted in a downstream longitudinal hawser force of 5 tons was 11.7 min. Chamber performance with an 18-ft lift was determined next during emptying. The average maximum hawser forces determined for these valve operations are plotted in Plate 59. The emptying time required to maintain hawser forces of 5 tons or less was 9.5 min.

Center of barges sta 8+40.5

The average maximum hawser forces determined during filling for 4-, 5-, and 8-min valve operations are plotted in Plate 58. The filling time required to maintain hawser forces of 5 tons or less was 11.3 min. The average maximum hawser forces determined during emptying for 1-, 2-, and 5-min valve operations are shown in Plate 59. The emptying time required to maintain hawser forces of 5 tons or less was 9.6 min.

The downstream longitudinal hawser forces measured during filling were slightly less with the barges located at sta 8+40.5. Centering the barges in the chamber helped reduce the downstream longitudinal hawser forces.

Outlet Diffuser and Lower Approach Experiments

The outlet diffuser was modified in an effort to distribute more flow along the floating guide wall. Experiments to complete the evaluation of the outlet and lower approach were performed in a separate flume and the results are reported in Hite (in preparation). This study found that a stilling basin with two rows of baffle blocks and an end sill surrounding the basin was effective in dissipating the energy from the outlet discharges. The discharge from the outlet was also directed in a downstream direction rather than normal to the bank to reduce the chances of bank erosion. Hawser forces measured on barges moored in the lower

approach during emptying with floating and solid guide walls were not excessive with the recommended outlet design.

4 Summary and Recommendations

The tow maneuverability tests showed that adding the two 7.5-ft-high by 30-ft-wide culverts in the upper half of the lock chamber did not affect the entry time for an upbound 15-barge tow drafted to 9 ft with a sill clearance of 16 ft (depth from lower pool to top of lower miter sill) and a culvert clearance of 11.5 ft (depth from lower pool to top of new culverts). The exit times for a downbound 15-barge tow drafted to 9 ft were affected with these same clearances. The exit time with a culvert clearance of 11.5 ft was increased approximately 40 percent over that without culverts in the chamber. The exit times were increased by only 5 percent when the culvert clearance was 17.5 ft.

The chamber performance experiments revealed that the permissible filling time with the type 1 design and the maximum lift of 18 ft was 11.8 min. The permissible emptying time with this lift was 9.3 min. Nonsynschronous valve operations did not improve the chamber performance with the type 1 design. Operations that reduced the filling time resulted in higher hawsers and operations that reduced the hawser forces resulted in longer filling times than those measured with the type 1 design and normal valve operations.

Head loss measurements with the type 1 design revealed the upstream filling system was much more efficient than the downstream filling system. Considerable head loss occurred in the intake, culvert , and culvert transition for the downstream filling system. The head losses for the emptying systems were similar. Observations of the free tow drift tests and water-surface elevations indicated flow conditions in the upper approach were satisfactory when filling both lock chambers simultaneously with 5-min valves. Much higher hawser forces were computed with a 2-min valve operation. Flow conditions in the lower approach were also satisfactory based on the free tow drift tests and the water-surface elevations.

The permissible filling time with the type 2 design and the 18-ft lift was 9.8 min. The modifications to the type 1 design that resulted in the type 2 design did not impact emptying performance. The head loss measured for the downstream filling system of the type 2 design was considerably lower than the type 1 design. Head losses through the intake and transition and the culverts accounted for the reduction. The permissible filling times determined for 16- and 12-ft lifts were 9.2 and 7.4 min, respectively. The overall lock coefficient determined for the type 2 design was 0.70 (compared to 0.63 for the type 1 design). This was

determined from the operation curve shown in Plate 57 for the 18-ft lift. This coefficient compares favorably with existing 1,200-ft-long by 110-ft-wide Corps locks. The chamber performance with the type 2 design was much faster and safer.

The maximum longitudinal hawser force measured for a 3 by 5 tow moored in the upper approach to the landside lock with both locks filling with an 18-ft lift and 2-min normal valves was 11.4 tons. The maximum hawser force computed from the tow weight component parallel to the water surface indicated slightly different results compared to the measured hawser forces. This was attributed to the uncertainty in the water-surface measurements. A more precise technique to measure the water-surface elevation would be needed to improve this method of estimating hawser forces. Guidance for the allowable hawser forces for this situation is not available. Additional research is recommended to determine the allowable forces for tows moored in lock approaches. Water-surface measurements and free tow drift tests indicated that flow conditions in the lower approach were not severe during emptying.

The final lock chamber experiments were performed with the extended lock chamber (1,381 ft from pintle to pintle). The permissible filling time with the 18-ft lift and the barges centered in the extended chamber was 11.3 min. Similarly, the permissible emptying time was 9.6 min. Slightly slower permissible filling times were determined with the barges centered 30 ft farther upstream.

As mentioned, results of the outlet experiments can be found in Hite (in preparation).

Extreme caution should be used if the lock is operated with one of the filling valves out of service. Water-surface slopes and hawser forces can become large if the valve is opened too fast. Hite et al. (in preparation) recommended a filling time of 18.2 min and a 9-min valve when using only the upper filling valve with an 18-ft lift for a 110-ft-wide by 1,320-ft- long lock.

The emptying experiments revealed that the clearance between the culvert in the upper half of the chamber and the bottom of a barge drafted to 9 ft was crucial to acceptable chamber performance. The barge may contact the culvert during the portion of the emptying operation when the water surface drops below the lower pool elevation. This can cause high hawser forces if the barges are not drafted similarly and could possibly damage the culvert. With a barge (9-ft draft) clearance of 1.5 ft (from top of culvert to bottom of barge at lower pool), rapid and significant increases in the upstream and downstream transverse hawser forces were measured during the under-emptying portion of the emptying operation. An increase in barge clearance of 1 ft (1.5 to 2.5) eliminated this occurrence.

The type 2 design filling and emptying system is recommended for the J. T. Myers filling and emptying system. The streamlined intake and larger culverts made significant improvements to the chamber performance. A minimum clearance of 2.5 ft from the bottom of a fully drafted barge to the top of the in-chamber culvert is recommended to prevent damage to the culvert and high hawser forces during the under-emptying portion of the emptying operation.

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Table 1
J. T. Myers Project Landside Lock General Information

Elevations (NGVD)	
Upper Pool	342
Lower Pool	324
Top Lock Wall	362
Lift (ft)	18
Culvert	
Size (ft)	14H - 16V
Area (sq ft)	224
Manifold-Valve Distance (ft)	458
Valve - 1st Lat Distance (ft)	121
Laterals	
Number	6
Spacing (ft)	36
Size @ Culvert, ft	9H - 6V
Area @ Culvert (sq ft)	54
Gross Area Lat (sq ft)	324
Ports	
Number per Lateral	18
Size	2H-2.17V
Area per Port (sq ft)	4.33
Port Area per Lat (sq ft)	78
Gross Port Area (sq ft)	468
Laterals	
Position - Coverage	
Upper Pintle - 1st Lat	0.328
Lock Coverage	0.269
Submergence/Clearances	
Upper Sill (ft)	34
Lower Sill (ft)	16
Top/Laterals (ft)	19.5
Top/Intake Manifold (ft)	18.5
System Ratios	
Gross Al/Ac	1.45
Gross Ap/Ac	2.09

Table 2
Comparison of Tow Maneuverability Results, Upper Pool el 342.0, Lower Pool el 324.0

Design Type	Tow Entry Speed	Tow Exit Speed
No Culverts in Chamber	1.4 ft/sec	1.8 ft/sec
Type 1 Design F & E	1.5 ft/sec	1.3 ft/sec
Difference	+0.1 ft/sec	-0.5 ft/sec

Note: Speed of tow determined when fourth row of barges crossed lower miter sill

Table 3
Loss Coefficients, J. T. Myers Type 1 Design F&E Systems

Filling Operations			
Upstream Filling System		**Downstream Filling System**	
System Component(s)	**Component Loss Coeff.**	**System Component(s)**	**Component Loss Coeff.**
Intake	0.28	Intake and Transitions	1.82
US Culvert and Valve Well	0.70	US Culvert	2.50
Manifold	0.94	Transition	1.41
		Culvert and Valve Well	0.17
		Manifold	0.93
Total	**1.92**	**Total**	**6.83**
Emptying Operations			
Upstream Emptying System		**Downstream Emptying System**	
System Component(s)	**Component Loss Coeff.**	**System Component(s)**	**Component Loss Coeff.**
Manifold	1.00	Manifold	1.10
DS Culvert, Valve and Outlet	2.03	DS Culvert, Valve and Outlet Manifold	1.88
Total	**3.03**	**Total**	**2.98**

Table 4
Upper Approach Free Tow Drift Tests

Upper Pool el	Lower Pool el	Valve Time, min	Gate Impact Time, min:sec	
			Type 1 Design	Type 2 Design
342	324	2	3:55	3:25
342	324	5	5:30	5:00
342	330	2	4:55	4:15
342	330	5	6:25	5:50

Table 5
Upper Approach - Landside Lock Extension, Type 1 Design F&E System, Upper Pool el 342, Lower Pool el 324

Time, sec	Water-Surface el, Dist. US LS Pintle, ft 1,158	Water-Surface el, Dist. US LS Pintle, ft 275	WS Diff., ft	Slope, ft/ft	Computed Hawser Force, tons
2-min Filling Valves					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.6	0.4	0.00045	13.0
100	341.9	341.4	0.5	0.00057	16.3
150	341.8	341.7	0.1	0.00011	3.3
200	341.8	341.7	0.1	0.00011	3.3
250	341.8	341.7	0.1	0.00011	3.3
300	341.9	341.9	0.0	0.00000	0.0
350	342.0	342.0	0.0	0.00000	0.0
400	342.0	342.0	0.0	0.00000	0.0
5-min Filling Valves					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.9	0.1	0.00011	3.3
100	342.0	341.8	0.2	0.00023	6.5
150	342.0	341.8	0.2	0.00023	6.5
200	341.9	341.8	0.1	0.00011	3.3
250	341.9	341.8	0.1	0.00011	3.3
300	341.9	341.8	0.1	0.00011	3.3
350	341.9	341.8	0.1	0.00011	3.3
400	342.0	341.9	0.1	0.00011	3.3
450	342.0	342.0	0.0	0.00000	0.0
500	342.0	342.0	0.0	0.00000	0.0

Note: Hawser forces computed for 3 by 5 barge arrangement

Table 6
Upper Approach Conditions - Landside Lock Extension, Type 1 Design F&E System, Upper Pool el 342, Lower Pool el 330

Time, sec	Water-Surface el, Dist. US LS Pintle, ft: 1,158	Water-Surface el, Dist. US LS Pintle, ft: 275	WS Diff., ft	Slope, ft/ft	Computed Hawser Force, tons
2-min Filling Valves					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.8	0.2	0.00023	6.5
100	341.9	341.6	0.3	0.00034	9.8
150	341.8	341.8	0.0	0.00000	0.0
200	341.9	341.8	0.1	0.00011	3.3
250	342.0	341.9	0.1	0.00011	3.3
300	342.0	342.0	0.0	0.00000	0.0
5-min Filling Valves					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.9	0.1	0.00011	3.3
100	342.0	341.9	0.1	0.00011	3.3
150	342.0	341.8	0.2	0.00023	6.5
200	342.0	341.8	0.2	0.00023	6.5
250	342.0	341.8	0.2	0.00023	6.5
300	342.0	341.8	0.2	0.00023	6.5
350	342.0	341.9	0.1	0.00011	3.3
400	342.0	342.0	0.0	0.00000	0.0

Note: Hawser forces computed for 3 by 5 barge arrangement

Table 7
Type 1 Design F&E System, Lower Approach Free Tow Drift Tests, 3 by 5 Tow with Head of Tow Located 102.5 ft DS of Lower Landside Pintle

Upper Pool el	Lower Pool el	Valve Time, min	Dist. Traveled DS, ft
342	324	2	48
342	324	5	55
342	330	2	15
342	330	5	16

Table 8
Water-Surface Elevations, Lower Approach - Landside Lock Extension, Type 1 Design F&E System, Upper Pool el 342, Lower Pool el 324

Time, sec	Water-Surface el DS of Landside Pintle, ft		
	102.5	**475**	**847.5**
2-min Empty Valve			
0	324.0	324.0	324.0
50	324.0	324.0	324.0
100	324.1	324.1	324.0
150	324.2	324.3	324.0
200	324.2	324.3	324.2
250	324.2	324.3	324.2
300	324.1	324.2	324.1
350	324.1	324.2	324.1
400	324.0	324.1	324.0
450	324.0	324.1	324.0
500	324.0	324.0	324.0
550	324.0	324.0	324.0
600	324.0	324.0	324.0
5-min Empty Valve			
0	324.0	324.0	324.0
50	324.0	324.0	324.0
100	324.0	324.1	324.0
150	324.1	324.1	324.0
200	324.1	324.2	324.1
250	324.2	324.3	324.1
300	324.2	324.3	324.2
350	324.1	324.2	324.1
400	324.1	324.2	324.1
450	324.1	324.1	324.1
500	324.0	324.1	324.0
550	324.0	324.0	324.0
600	324.0	324.0	324.0

Table 9
Water-Surface Elevations, Lower Approach - Landside Lock Extension, Type 1 Design F&E System Upper Pool el 342, Lower Pool el 330

Time, sec	Water-Surface el DS of Landside Pintle, ft 102.5	475	847.5
2-min Empty Valve			
0	330.0	330.0	330.0
50	330.0	330.0	330.0
100	330.1	330.1	330.0
150	330.1	330.1	330.0
200	330.2	330.1	330.0
250	330.2	330.2	330.0
300	330.2	330.2	330.0
350	330.2	330.2	330.0
400	330.1	330.1	330.0
450	330.1	330.1	330.0
500	330.0	330.0	330.0
5-min Empty Valve			
0	330.0	330.0	330.0
50	330.0	330.0	330.0
100	330.0	330.0	330.0
150	330.1	330.1	330.0
200	330.1	330.1	330.0
250	330.2	330.2	330.0
300	330.2	330.2	330.0
350	330.1	330.1	330.0
400	330.0	330.0	330.0

Table 10
J. T. Myers F&E System, Comparison of Loss Coefficients

Filling Operations			
Type 1 Design Filling System		**Type 2 Design Filling System**	
System Component(s)	**Component Loss Coeff.**	**System Component(s)**	**Component Loss Coeff.**
Intake and Transitions	1.82	Intake and Transitions	0.27
US Culvert	2.50	US Culvert	1.13
Transition	1.41	Transition	1.24
Culvert and Valve Well	0.17	Culvert and Valve Well	0.15
Manifold	0.93	Manifold	0.95
Total	**6.83**	**Total**	**3.74**

Table 11
Upper Approach - Landside Lock Extension, Type 2 Design F&E System, Upper Pool el 342, Lower Pool el 324

Time, sec	Water-Surface el, Dist. US LS Pintle, ft: 1,158	275	WS Diff., ft	Slope, ft/ft	Computed Hawser Force, tons
2-min Filling Valves for Both Locks					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.8	0.2	0.00023	6.5
100	341.9	341.6	0.3	0.00034	9.8
150	341.6	341.6	0.0	0.00000	0.0
200	341.3	341.3	0.0	0.00000	0.0
250	341.2	341.2	0.0	0.00000	0.0
300	341.1	341.1	0.0	0.00000	0.0
350	341.0	341.0	0.0	0.00000	0.0
400	341.1	341.1	0.0	0.00000	0.0
450	341.2	341.2	0.0	0.00000	0.0
500	341.4	341.4	0.0	0.00000	0.0
550	341.7	341.6	0.1	0.00011	3.3
600	341.9	341.8	0.1	0.00011	3.3
650	342.0	341.9	0.1	0.00011	3.3
700	342.0	342.0	0.0	0.00000	0.0
750	342.0	342.0	0.0	0.00000	0.0
5-min Filling Valves for Both Locks					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.9	0.1	0.00011	3.3
100	342.0	341.9	0.1	0.00011	3.3
150	342.0	341.8	0.2	0.00023	6.5
200	341.9	341.7	0.2	0.00023	6.5
250	341.7	341.5	0.2	0.00023	6.5
300	341.5	341.4	0.1	0.00011	3.3
350	341.3	341.3	0.0	0.00000	0.0
400	341.2	341.2	0.0	0.00000	0.0
450	341.3	341.3	0.0	0.00000	0.0
500	341.4	341.4	0.0	0.00000	0.0
550	341.5	341.5	0.0	0.00000	0.0
600	341.7	341.7	0.0	0.00000	0.0
650	341.9	341.8	0.1	0.00011	3.3
700	342.0	341.9	0.1	0.00011	3.3
750	342.0	342.0	0.0	0.00000	0.0

Note: Hawser forces computed for 3 by 5 barge arrangement

Table 12
Upper Approach - Landside Lock Extension, Type 2 Design F&E System, Upper Pool el 342, Lower Pool el 324, Landside Lock Only

Time, sec	Water-Surface el, Dist. US LS Pintle, ft: 1,158	Water-Surface el, Dist. US LS Pintle, ft: 275	WS Diff., ft	Slope, ft/ft	Computed Hawser Force, tons
2-min Filling Valves					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	341.9	0.1	0.00011	3.3
100	342.0	341.9	0.1	0.00011	3.3
150	341.9	341.8	0.1	0.00011	3.3
200	341.8	341.8	0.0	0.00000	0.0
250	341.9	341.8	0.1	0.00011	3.3
300	341.9	341.9	0.0	0.00000	0.0
350	341.9	341.9	0.0	0.00000	0.0
400	341.9	341.9	0.0	0.00000	0.0
450	342.0	341.9	0.1	0.00011	3.3
500	342.0	341.9	0.1	0.00011	3.3
550	342.0	342.0	0.0	0.00000	0.0
600	342.0	342.0	0.0	0.00000	0.0
5-min Filling Valves					
0	342.0	342.0	0.0	0.00000	0.0
50	342.0	342.0	0.0	0.00000	0.0
100	342.0	341.9	0.1	0.00011	3.3
150	342.0	341.9	0.1	0.00011	3.3
200	341.9	341.8	0.1	0.00011	3.3
250	341.9	341.8	0.1	0.00011	3.3
300	341.9	341.8	0.1	0.00011	3.3
350	341.9	341.8	0.1	0.00011	3.3
400	341.9	341.8	0.1	0.00011	3.3
450	341.9	341.9	0.0	0.00000	0.0
500	342.0	341.9	0.1	0.00011	3.3
550	342.0	342.0	0.0	0.00000	0.0
600	342.0	342.0	0.0	0.00000	0.0

Note: Hawser forces computed for 3 by 5 barge arrangement

Table 13
Hawser Force Measurements, Upper Approach, Main and Auxiliary Lock Filling, Type 2 Design, F&E System, 18-ft Lift, Upper Pool el 342, Lower Pool el 324

Valve Time, min	Hawser Forces, tons					
	Longitudinal		US Transverse		DS Transverse	
	US	DS	Right	Left	Right	Left
	3.1	-11.4	0.9	-1.2	1.4	-0.9
2.0	3.0	-11.3	0.8	-0.7	1.2	-1.3
	2.7	-11.4	1.0	-1.0	1.5	-1.3
Average	2.9	-11.4	0.9	-1.0	1.4	-1.2
	1.9	-5.5	0.9	-1.0	1.1	-1.3
4.0	2.0	-5.8	0.7	-0.9	0.9	-1.1
	2.2	-5.9	0.7	-0.8	0.8	-0.9
Average	2.0	-5.7	0.8	-0.9	0.9	-1.1
	2.2	-4.9	1.0	-0.6	1.0	-1.1
5.0	2.0	-4.5	1.3	-0.9	1.4	-1.5
	2.4	-4.7	0.9	-0.7	1.0	-1.1
Average	2.2	-4.7	1.1	-0.7	1.1	-1.2

Table 14
Hawser Force Measurements, Upper Approach, Main and Auxiliary Lock Filling, Type 2 Design F&E System, 12-ft Lift, Upper Pool el 342, Lower Pool el 330

Valve Time, min	Maximum Hawser Forces, tons					
	Longitudinal		US Transverse		DS Transverse	
	US	DS	Right	Left	Right	Left
	3.3	-9.6	0.8	-1.4	1.4	-1.1
2.0	2.9	-9.0	1.0	-1.5	1.4	-1.0
	3.1	-9.3	0.8	-1.2	1.4	-1.0
Average	3.1	-9.3	0.9	-1.4	1.4	-1.0
	2.2	-4.6	1.0	-1.2	1.1	-0.8
4.0	2.0	-4.3	0.8	-1.0	1.2	-0.8
	2.3	-4.4	1.2	-1.1	1.1	-1.4
Average	2.2	-4.4	1.0	-1.1	1.1	-1.0
	1.9	-3.7	1.0	-0.8	1.0	-1.2
5.0	2.1	-3.6	0.7	-0.6	0.9	-0.9
	1.9	-3.5	0.9	-0.6	1.1	-0.9
Average	2.0	-3.6	0.9	-0.7	1.0	-1.0

Table 15
Hawser Force Measurements, Upper Approach, Landside Lock Filling, Type 2 Design F&E System, 18-ft Lift, Upper Pool el 342, Lower Pool el 324

Valve Time, min	Maximum Hawser Forces, tons					
	Longitudinal		US Transverse		DS Transverse	
	US	DS	Right	Left	Right	Left
2.0	1.4	-7.0	0.9	-0.8	1.6	-1.1
	1.1	-6.9	0.8	-1.1	1.3	-1.4
	1.3	-7.4	0.8	-0.9	1.5	-1.6
Average	1.3	-7.1	0.8	-0.9	1.5	-1.4
4.0	1.1	-3.7	0.8	-1.1	1.4	-1.3
	1.2	-4.1	1.4	-0.9	1.3	-1.4
	1.3	-3.9	1.0	-1.0	1.4	-1.2
Average	1.2	-3.9	1.1	-1.0	1.4	-1.3
8.0	1.5	-2.3	1.1	-1.1	1.5	-1.5
	1.1	-2.1	0.6	-0.8	1.1	-1.1
	1.3	-2.3	0.7	-1.0	1.0	-1.1
Average	1.3	-2.2	0.8	-1.0	1.2	-1.2

Table 16
Hawser Force Measurements, Upper Approach, Landside Lock Filling, Type 2 Design F&E System, 12-ft Lift, Upper Pool el 342, Lower Pool el 330

Valve Time, min	Maximum Hawser Forces, tons					
	Longitudinal		US Transverse		DS Transverse	
	US	DS	Right	Left	Right	Left
2.0	1.1	-5.3	0.9	-0.9	1.6	-1.1
	1.1	-5.4	1.0	-1.2	1.4	-1.4
	1.1	-5.6	0.9	-0.7	1.2	-1.2
Average	1.1	-5.4	0.9	-0.9	1.4	-1.2
4.0	1.1	-2.8	0.8	-0.5	0.8	-0.9
	1.1	-2.5	0.8	-0.4	0.9	-0.9
	0.9	-2.5	0.8	-0.4	1.2	-0.9
Average	1.0	-2.6	0.8	-0.4	1.0	-0.9
5.0	1.1	-2.3	0.7	-0.9	1.3	-0.8
	1.2	-2.5	0.8	-0.8	1.3	-0.8
	1.0	-2.4	1.1	-0.7	1.0	-1.0
Average	1.1	-2.4	0.9	-0.8	1.2	-0.9

Table 17
Type 2 Lower Approach, Lower Approach Free Tow Drift Tests

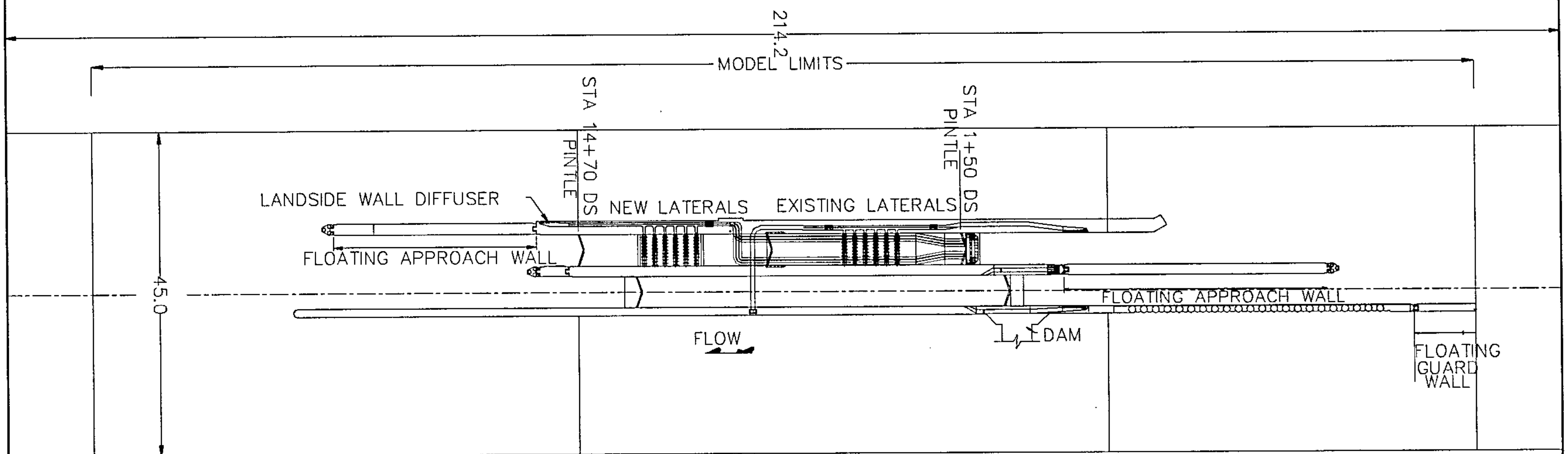
Upper Pool el	Lower Pool el	Valve Time, min	Distance Traveled DS, ft
3 by 5 Tow with Head of Tow Located 102.5 ft DS of Pintle			
342	324	1	8.8
342	324	2	10.8
342	330	1	7.5
342	330	2	4.5
3 by 5 Tow with Head of Tow Located 296.0 ft DS of Pintle			
342	324	1	12.5
342	324	2	13.3
342	330	1	7.5
342	330	2	5.0
3 by 5 Tow with Head of Tow Located 296.0 ft DS of Pintle on River Wall			
342	324	1	15.8
342	324	2	12.0
342	330	1	15.0
342	330	2	7.5

Table 18
Water-Surface Elevations, Lower Approach - Landside Lock Extension, Type 2 Lower Approach, Upper Pool el 342, Lower Pool el 324

Time sec	Water-Surface el DS of Landside Pintle, ft		
	102.5	475	847.5
1-min Empty Valve			
0	324.0	324.0	324.0
50	324.0	324.0	324.0
100	324.0	324.1	324.0
150	324.0	324.1	324.1
200	324.0	324.2	324.1
250	324.0	324.2	324.1
300	324.0	324.2	324.1
350	324.0	324.2	324.1
400	324.0	324.1	324.0
450	324.0	324.1	324.0
500	324.0	324.0	324.0
550	324.0	324.0	324.0
600	324.0	324.0	324.0
650	324.0	324.0	324.0
700	324.0	324.0	324.0
750	324.0	324.0	324.0
800	324.0	324.0	324.0
2-min Empty Valve			
0	324.0	324.0	324.0
50	324.0	324.0	324.0
100	324.0	324.0	324.0
150	324.0	324.2	324.1
200	324.0	324.2	324.1
250	324.0	324.2	324.1
300	324.0	324.2	324.1
350	324.0	324.1	324.0
400	324.0	324.1	324.0
450	324.0	324.1	324.0
500	324.0	324.0	324.0
550	324.0	324.0	324.0
600	324.0	324.0	324.0
650	324.0	324.0	324.0
700	324.0	324.0	324.0
750	324.0	324.0	324.0
800	324.0	324.0	324.0

Table 19
Water-Surface Elevations, Lower Approach - Landside Lock Extension, Type 2 Lower Approach, Upper Pool el 342, Lower Pool el 330

Time, sec	Water-Surface el DS of Landside Pintle, ft		
	102.5	475	847.5
1-min Empty Valve			
0	330.0	330.0	330.0
50	330.0	330.0	330.0
100	330.0	330.0	330.0
150	330.0	330.1	330.0
200	330.0	330.1	330.1
250	330.1	330.1	330.1
300	330.1	330.1	330.1
350	330.0	330.1	330.1
400	330.0	330.0	330.0
450	330.0	330.0	330.0
500	330.0	330.0	330.0
550	330.0	330.0	330.0
600	330.0	330.0	330.0
650	330.0	330.0	330.0
700	330.0	330.0	330.0
750	330.0	330.0	330.0
800	330.0	330.0	330.0
2-min Empty Valve			
0	330.0	330.0	330.0
50	330.0	330.0	330.0
100	330.0	330.1	330.0
150	330.0	330.1	330.0
200	330.0	330.1	330.1
250	330.0	330.1	330.1
300	330.0	330.1	330.1
350	330.0	330.1	330.0
400	330.0	330.0	330.0
450	330.0	330.0	330.0
500	330.0	330.0	330.0
550	330.0	330.0	330.0
600	330.0	330.0	330.0
650	330.0	330.0	330.0
700	330.0	330.0	330.0
750	330.0	330.0	330.0
800	330.0	330.0	330.0



PLAN OF F&E SYSTEM MODEL

NOTE: DIMENSIONS ARE IN FT

LAYOUT OF
J. T. MYERS
LOCK FILLING AND EMPTYING MODEL

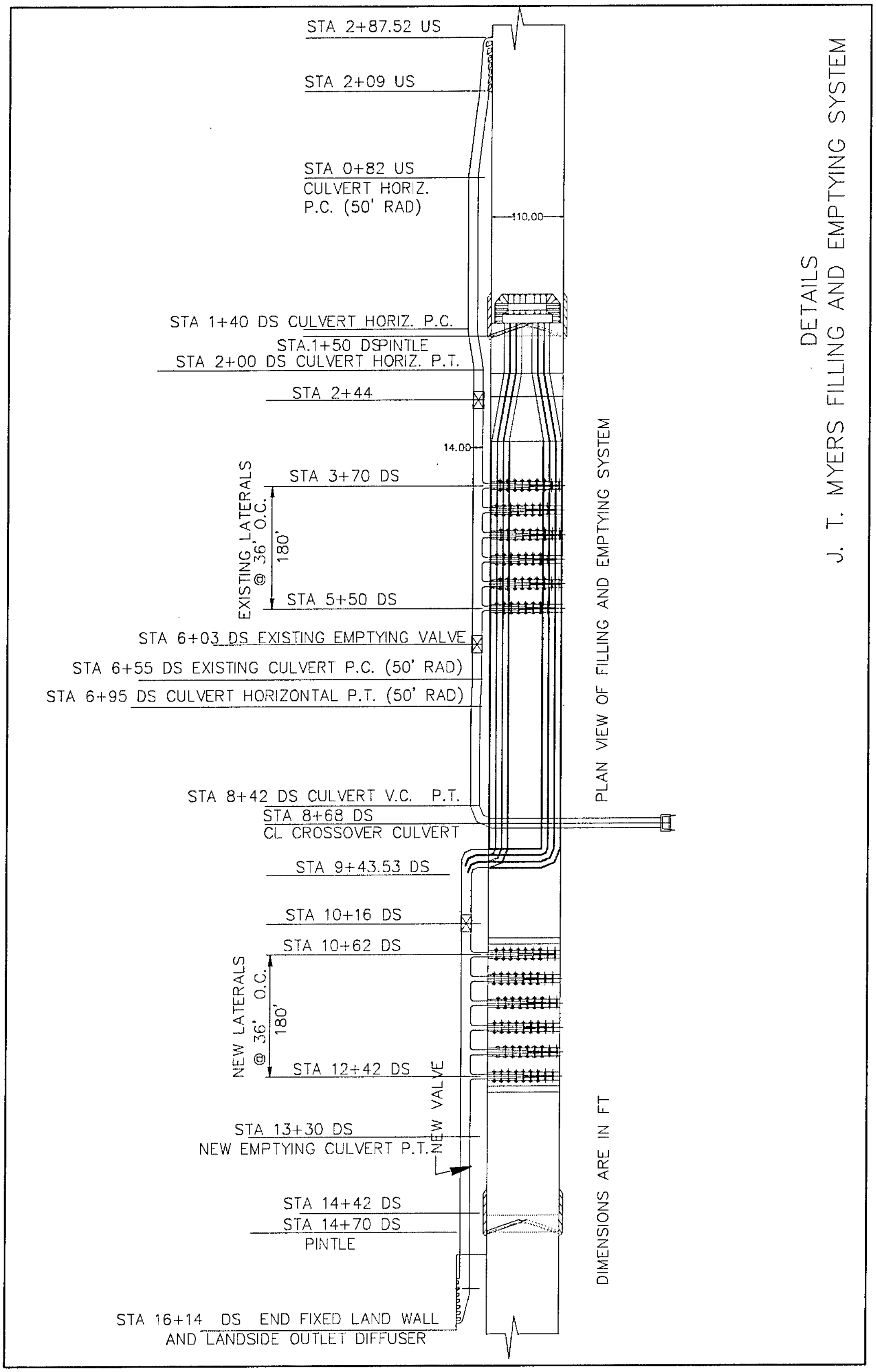
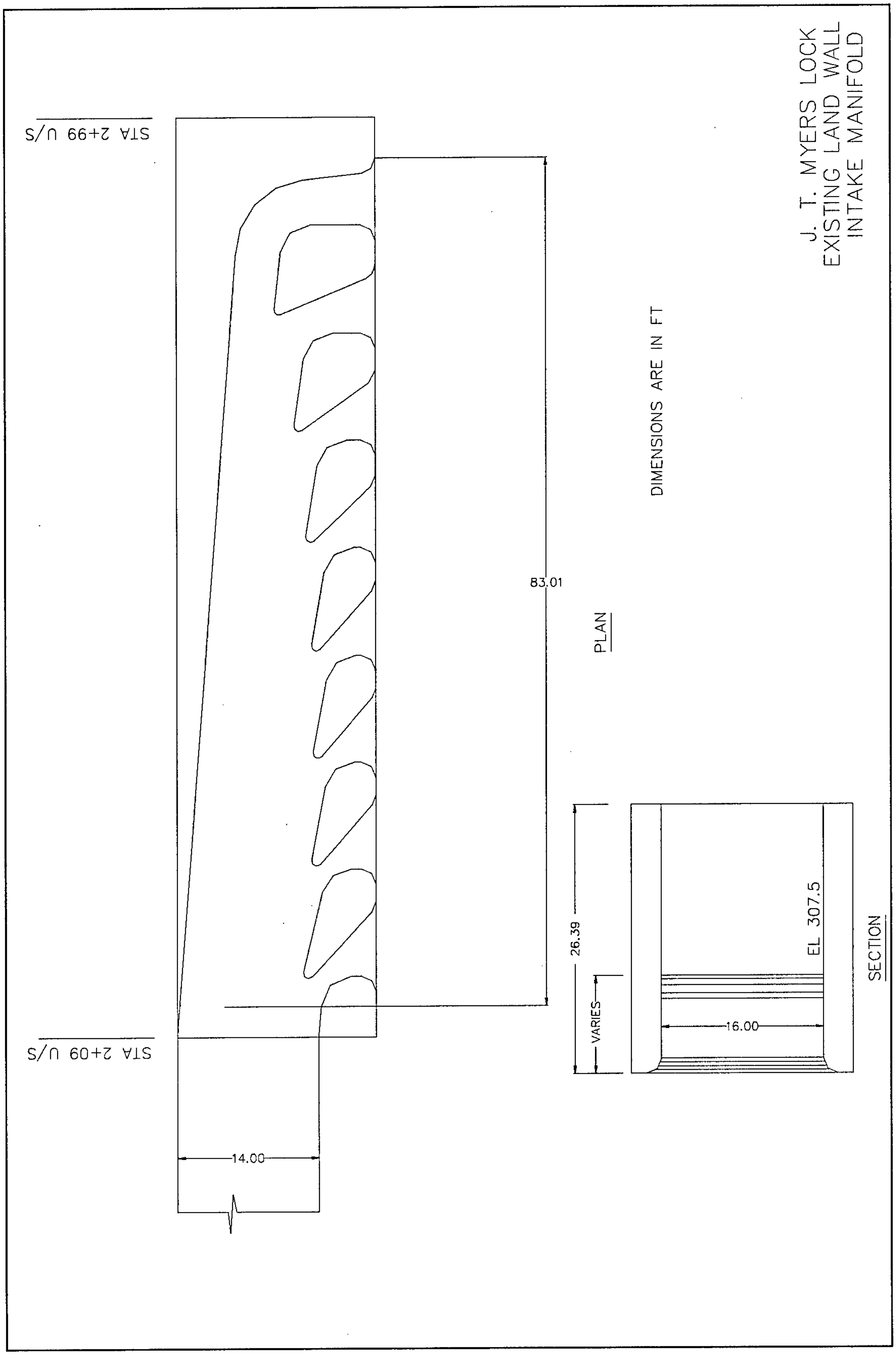

DETAILS
J. T. MYERS FILLING AND EMPTYING SYSTEM
PLAN VIEW OF FILLING AND EMPTYING SYSTEM
DIMENSIONS ARE IN FT
STA 2+87.52 US
STA 2+09 US
STA 0+82 US
CULVERT HORIZ.
P.C. (50' RAD)
110.00
STA 1+40 DS CULVERT HORIZ. P.C.
STA.1+50 DSPINTLE
STA 2+00 DS CULVERT HORIZ. P.T.
STA 2+44
14.00
STA 3+70 DS
EXISTING LATERALS
@ 36' O.C.
180'
STA 5+50 DS
STA 6+03 DS EXISTING EMPTYING VALVE
STA 6+55 DS EXISTING CULVERT P.C. (50' RAD)
STA 6+95 DS CULVERT HORIZONTAL P.T. (50' RAD)
STA 8+42 DS CULVERT V.C. P.T.
STA 8+68 DS
CL CROSSOVER CULVERT
STA 9+43.53 DS
STA 10+16 DS
STA 10+62 DS
NEW LATERALS
@ 36' O.C.
180'
STA 12+42 DS
NEW VALVE
STA 13+30 DS
NEW EMPTYING CULVERT P.T.
STA 14+42 DS
STA 14+70 DS
PINTLE
STA 16+14 DS END FIXED LAND WALL
AND LANDSIDE OUTLET DIFFUSER

Plate 2



J. T. MYERS LOCK
EXISTING LAND WALL
INTAKE MANIFOLD
DIMENSIONS ARE IN FT
STA 2+99 U/S
STA 2+09 U/S
83.01
PLAN
14.00
26.39
VARIES
16.00
EL 307.5
SECTION

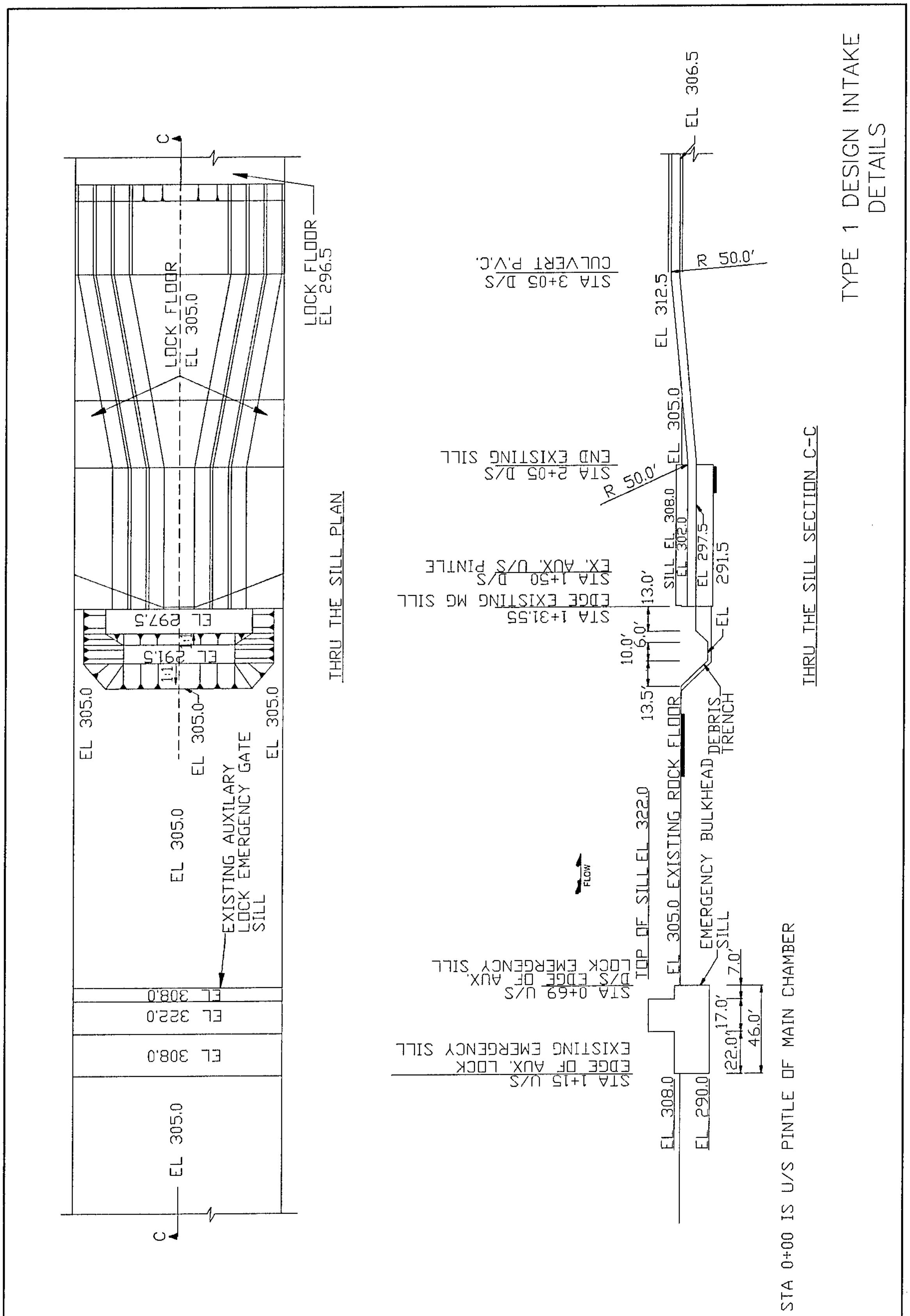
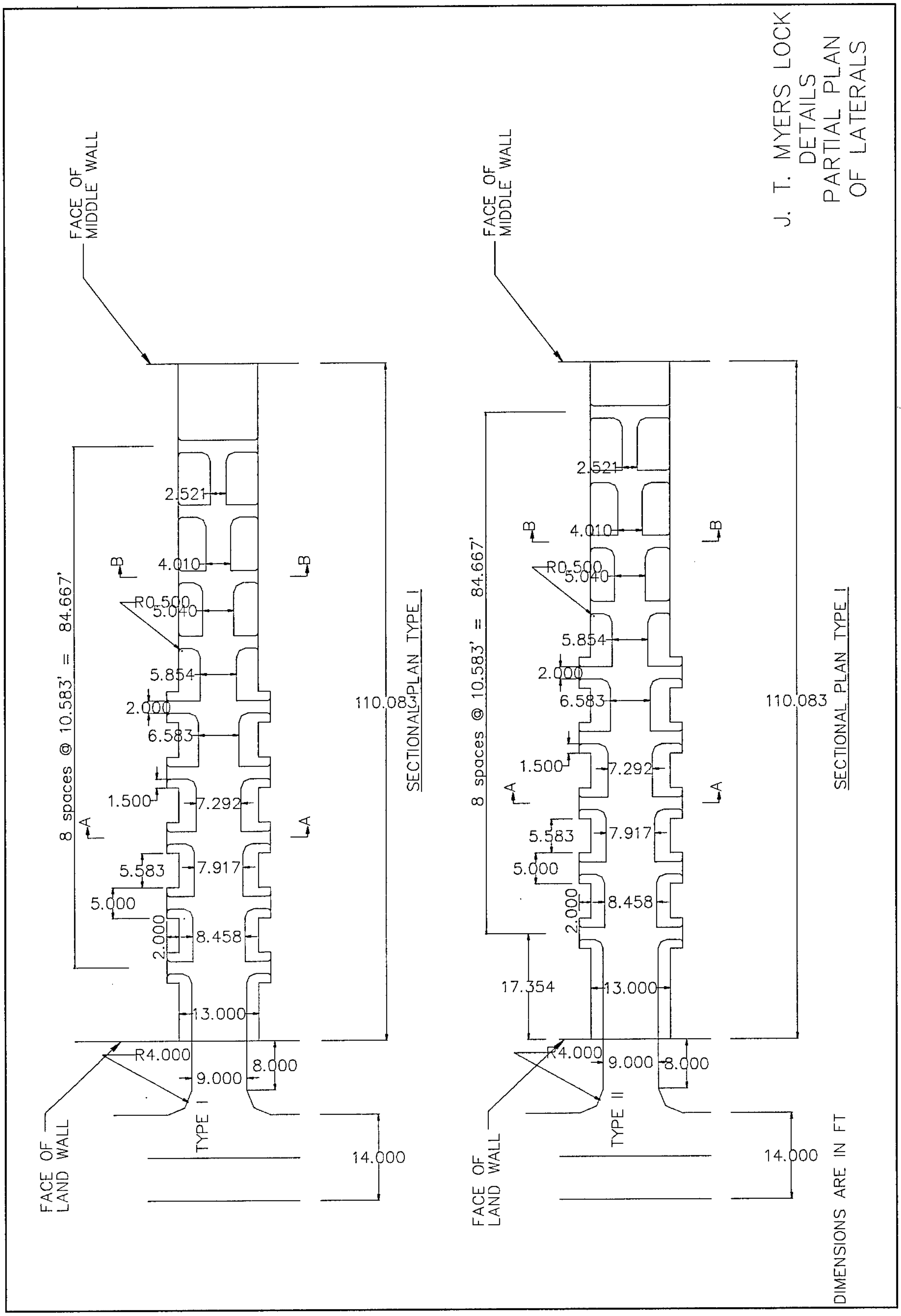

TYPE 1 DESIGN INTAKE DETAILS
THRU THE SILL PLAN
THRU THE SILL SECTION C-C
LOCK FLOOR EL 305.0
LOCK FLOOR EL 296.5
EL 297.5
EL 291.5
EL 305.0
EXISTING AUXILARY LOCK EMERGENCY GATE SILL
EL 308.0
EL 322.0
STA 3+05 D/S CULVERT P.V.C.
STA 2+05 D/S END EXISTING SILL
STA 1+50 D/S EX. AUX. U/S PINTLE
STA 1+31.55 EDGE EXISTING MG SILL
STA 0+69 U/S D/S EDGE OF AUX. LOCK EMERGENCY SILL
STA 1+15 U/S EDGE OF AUX. LOCK EXISTING EMERGENCY SILL
EL 306.5
R 50.0'
EL 312.5
SILL EL 308.0
EL 302.0
EL 297.5
EL 291.5
DEBRIS TRENCH
EMERGENCY BULKHEAD
EL 305.0 EXISTING ROCK FLOOR
TOP OF SILL EL 322.0
EMERGENCY SILL
FLOW
13.0'
6.0'
10.0'
13.5'
7.0'
17.0'
22.0'
46.0'
EL 308.0
EL 290.0
STA 0+00 IS U/S PINTLE OF MAIN CHAMBER

Plate 4


J. T. MYERS LOCK
DETAILS
PARTIAL PLAN
OF LATERALS
FACE OF MIDDLE WALL
FACE OF LAND WALL
8 spaces @ 10.583' = 84.667'
110.083
SECTIONAL PLAN TYPE I
TYPE I
TYPE II
2.521
4.010
5.040
5.854
6.583
7.292
7.917
8.458
13.000
R0.500
2.000
1.500
5.583
5.000
17.354
R4.000
9.000
8.000
14.000
A
B
DIMENSIONS ARE IN FT

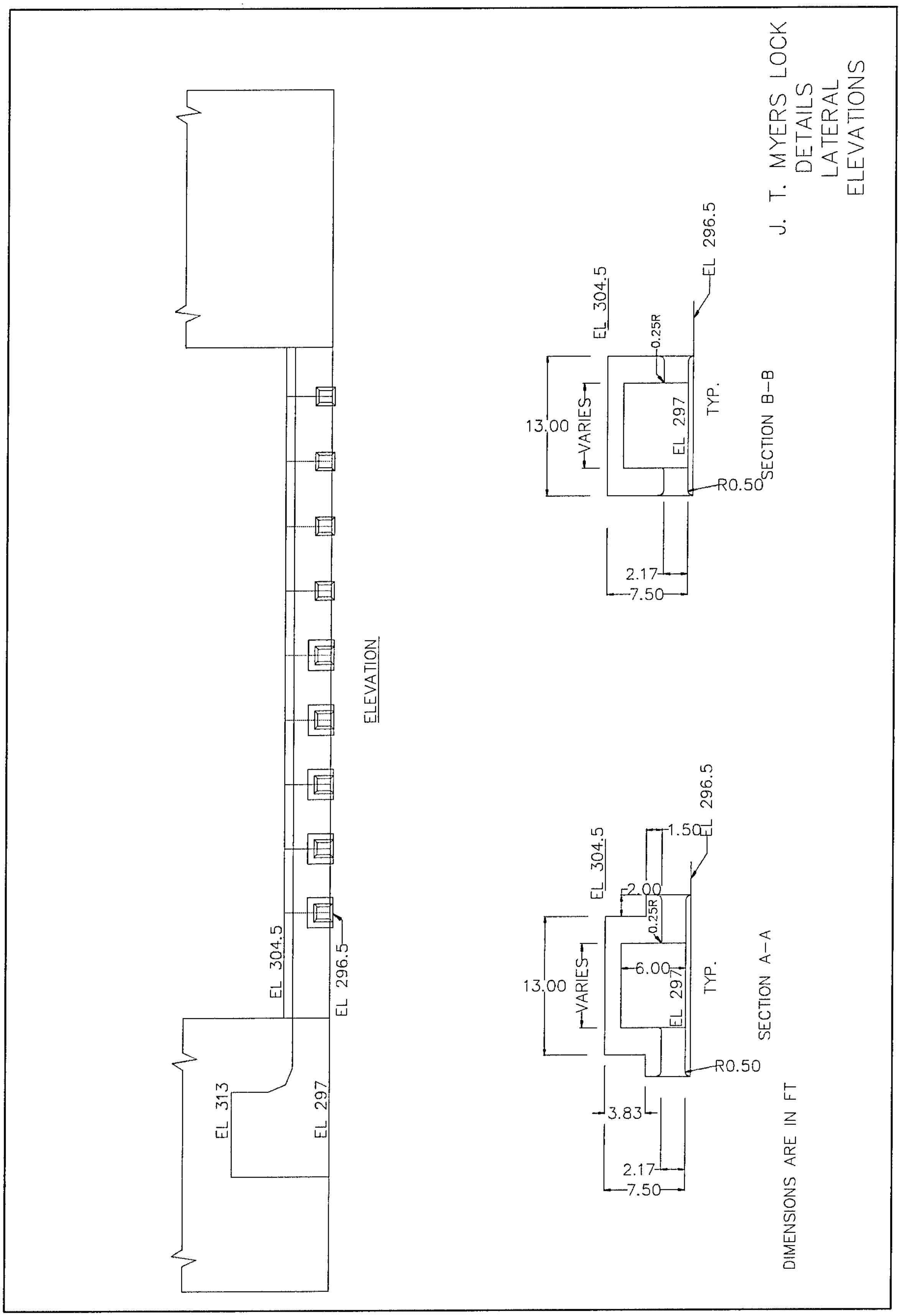
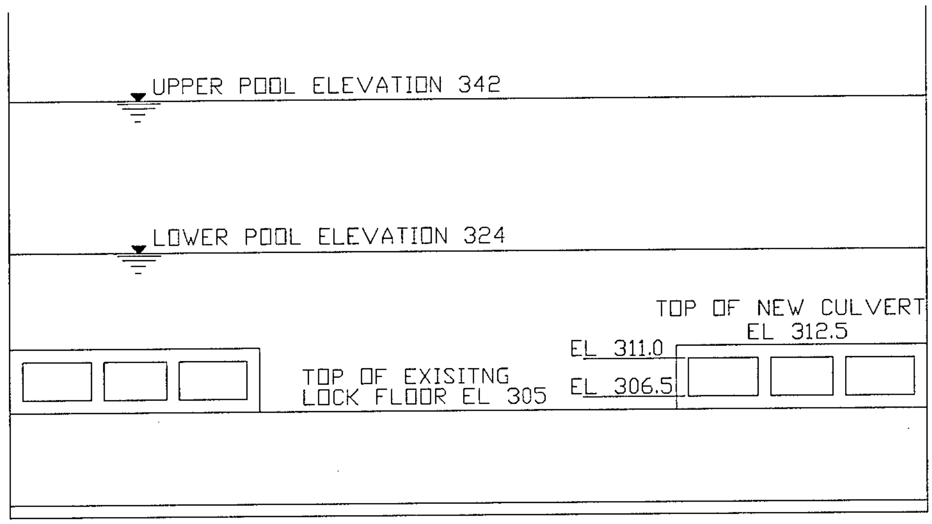
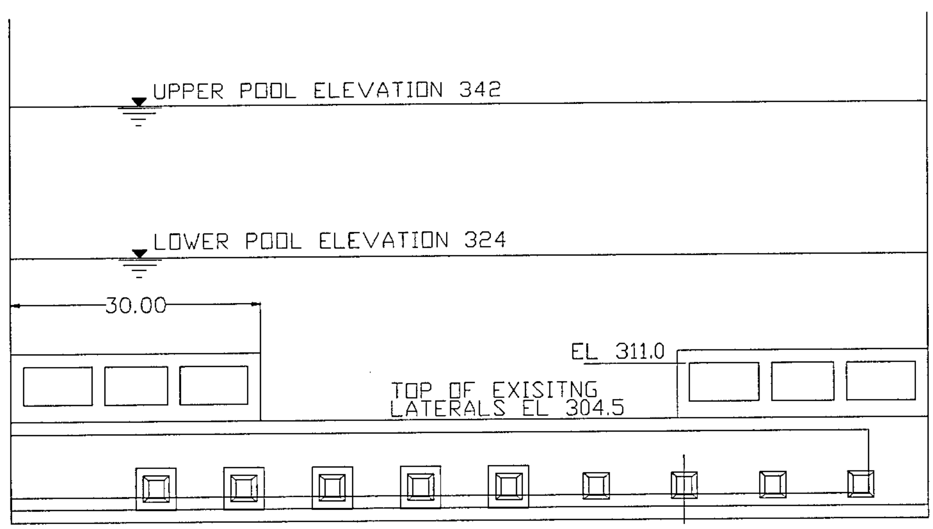

J. T. MYERS LOCK
DETAILS
LATERAL
ELEVATIONS
ELEVATION
EL 304.5
EL 296.5
EL 313
EL 297
SECTION A–A
SECTION B–B
13.00
VARIES
2.00
0.25R
6.00
EL 297
TYP.
1.50
R0.50
3.83
2.17
7.50
DIMENSIONS ARE IN FT

Plate 6



SECTION OF NEW SUPPLEMENTAL CULVERT
BETWEEN STA 2+55 D/S AND EXISTING LATERALS



SECTION OF NEW SUPPLEMENTAL CULVERT
OVER EXISTING LATERAL SYSTEM SECTION

J. T. MYERS
CROSS SECTIONS
THROUGH LOCK

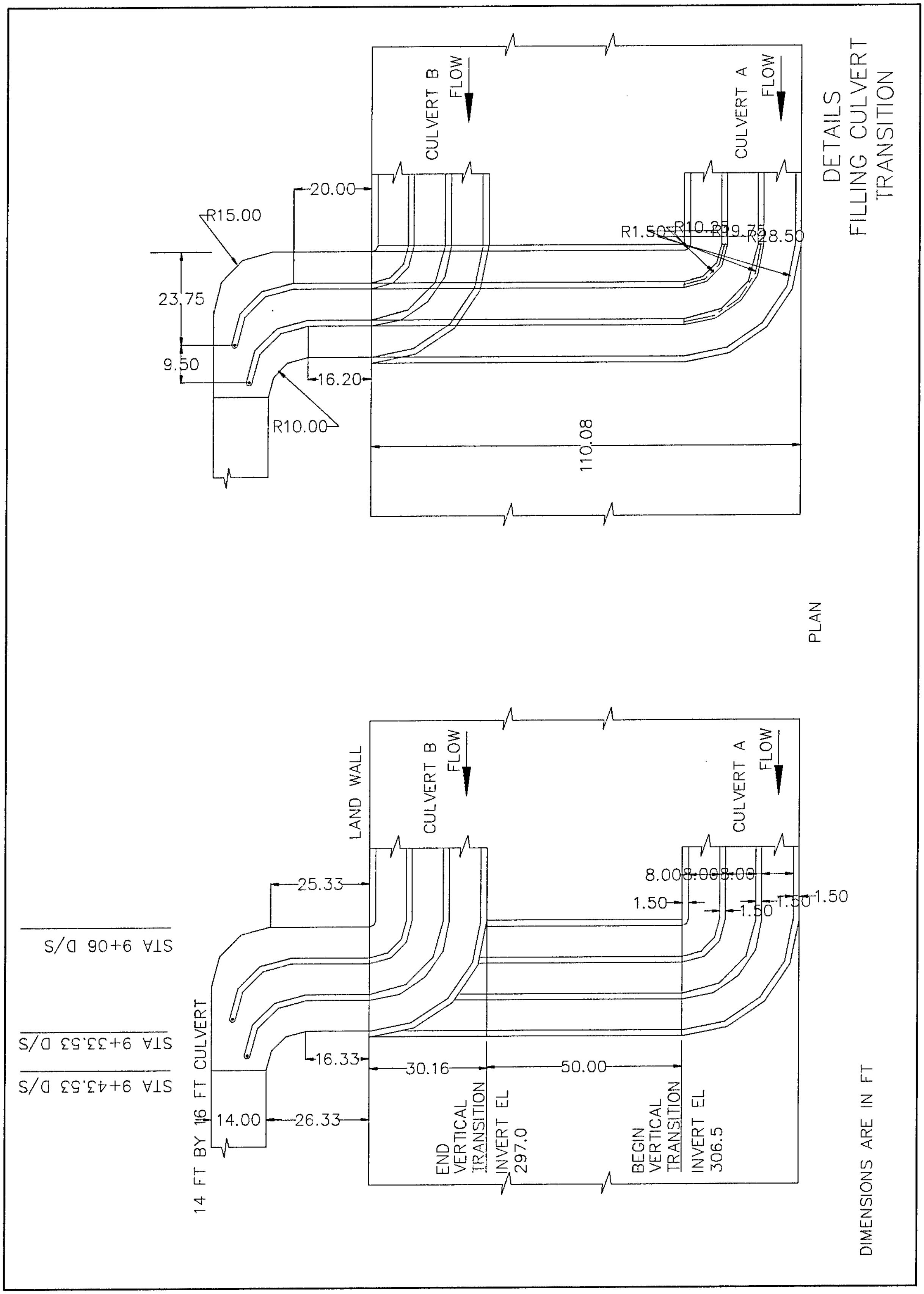
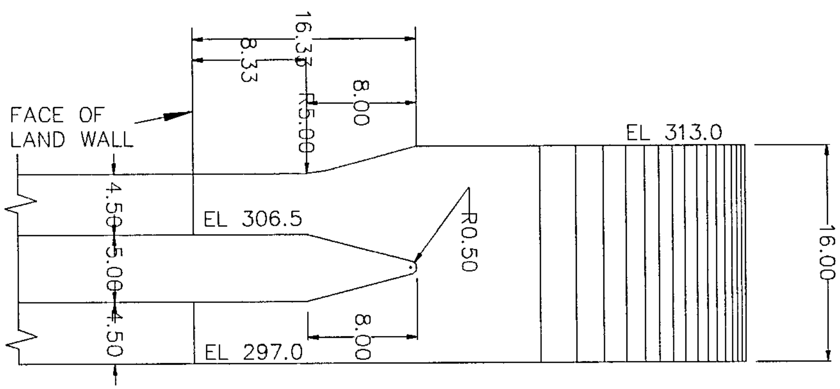
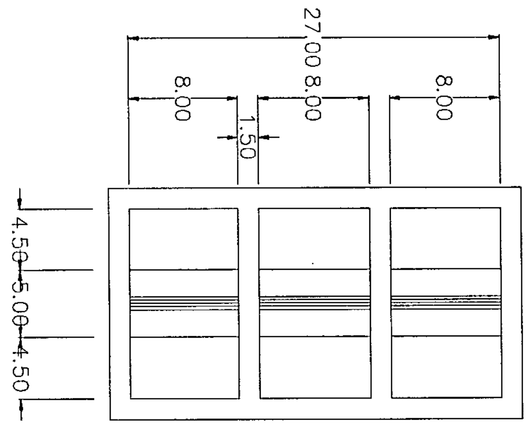

DETAILS
FILLING CULVERT
TRANSITION
CULVERT B
FLOW
CULVERT A
FLOW
R15.00
20.00
23.75
9.50
16.20
R10.00
R1.50
R10.25
R19.75
R28.50
110.08
PLAN
LAND WALL
CULVERT B
FLOW
CULVERT A
FLOW
25.33
8.00
8.00
8.00
1.50
1.50
1.50
1.50
16.33
30.16
50.00
14.00
26.33
14 FT BY 16 FT CULVERT
STA 9+06 D/S
STA 9+33.53 D/S
STA 9+43.53 D/S
END
VERTICAL
TRANSITION
INVERT EL
297.0
BEGIN
VERTICAL
TRANSITION
INVERT EL
306.5
DIMENSIONS ARE IN FT

Plate 8



VERTICAL TRANSITION SECTION



SECTION AT FACE OF LOCK WALL

DETAILS
FILLING CULVERTS
TRANSITION TO SINGLE CULVERT

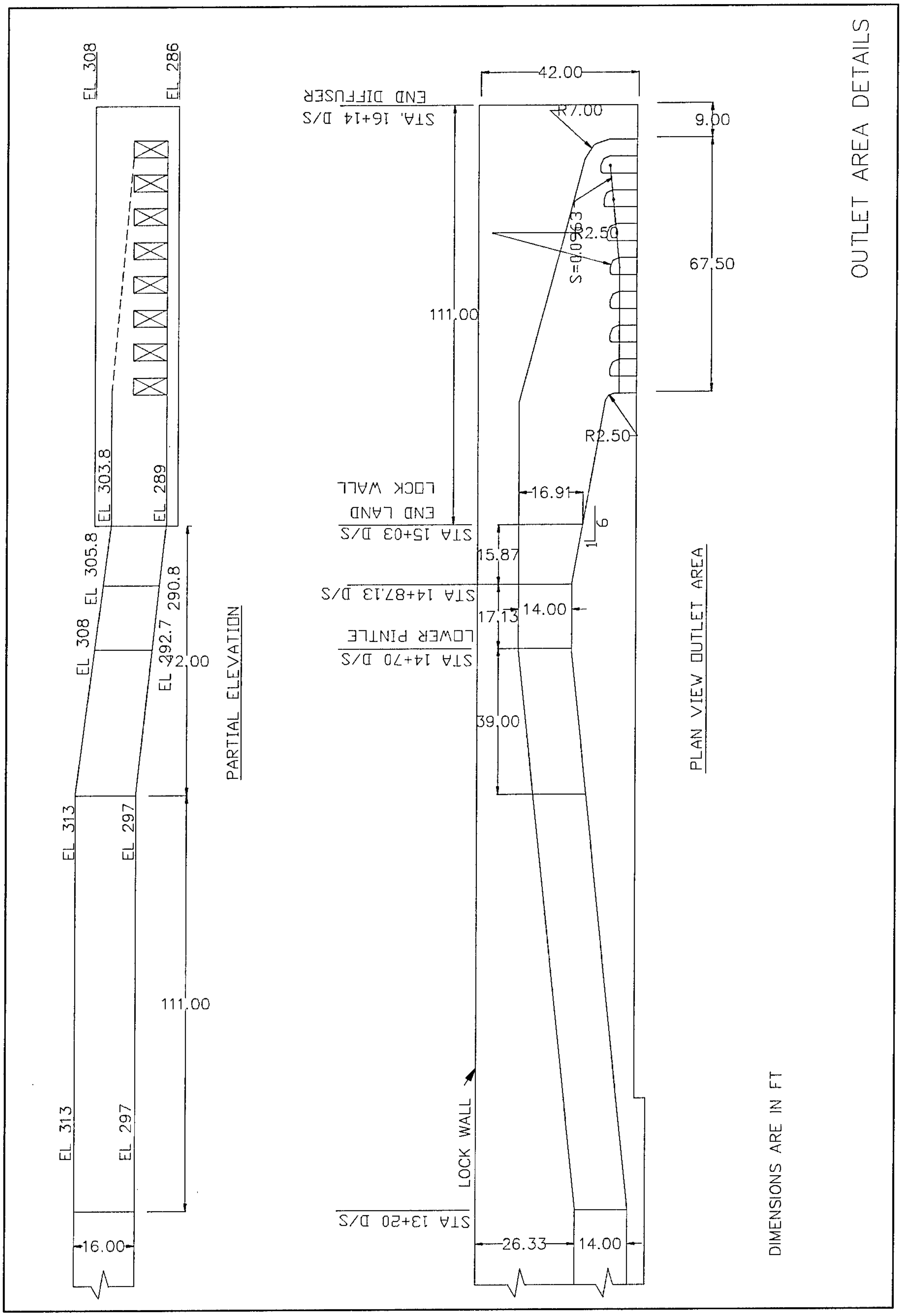
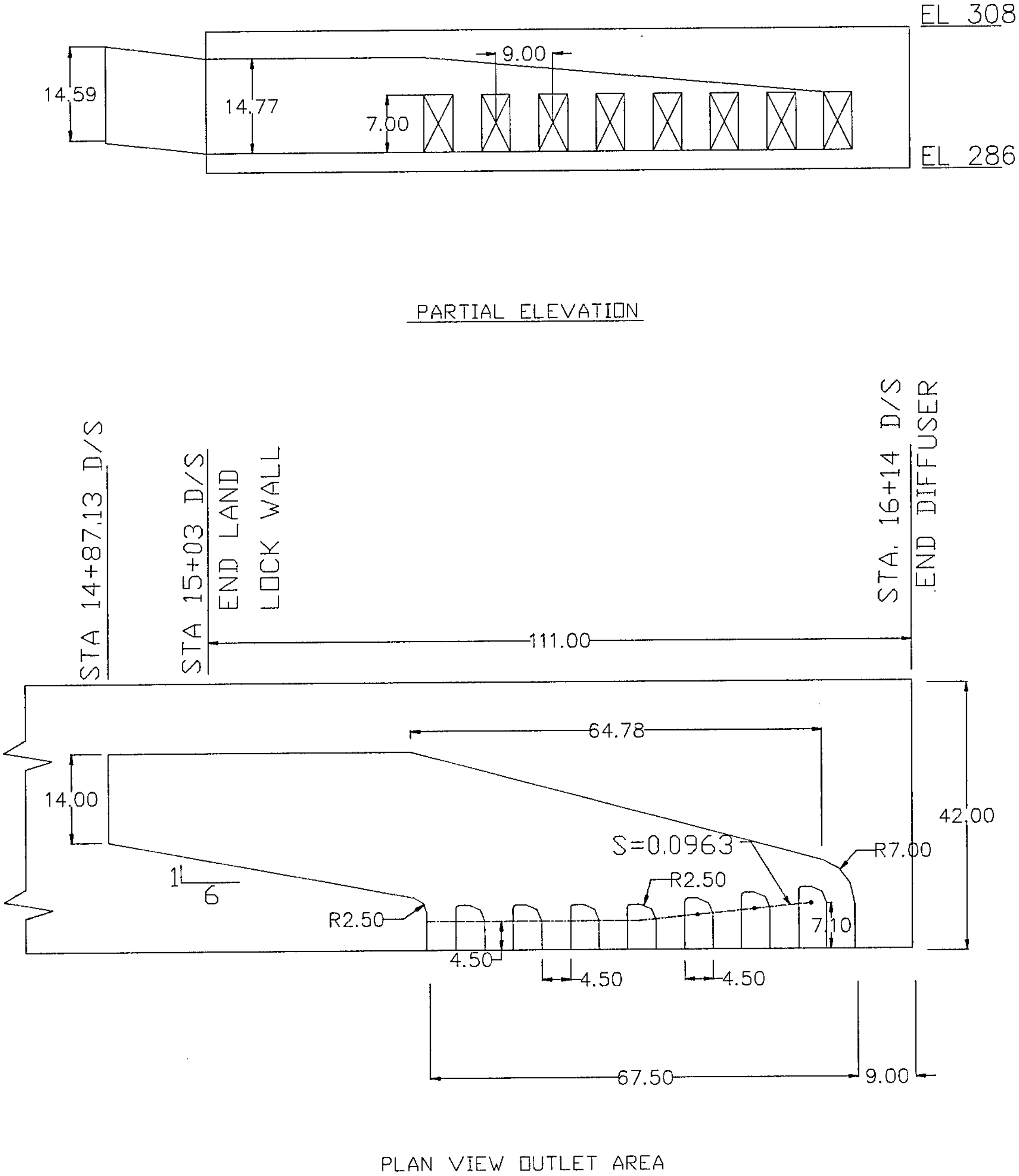
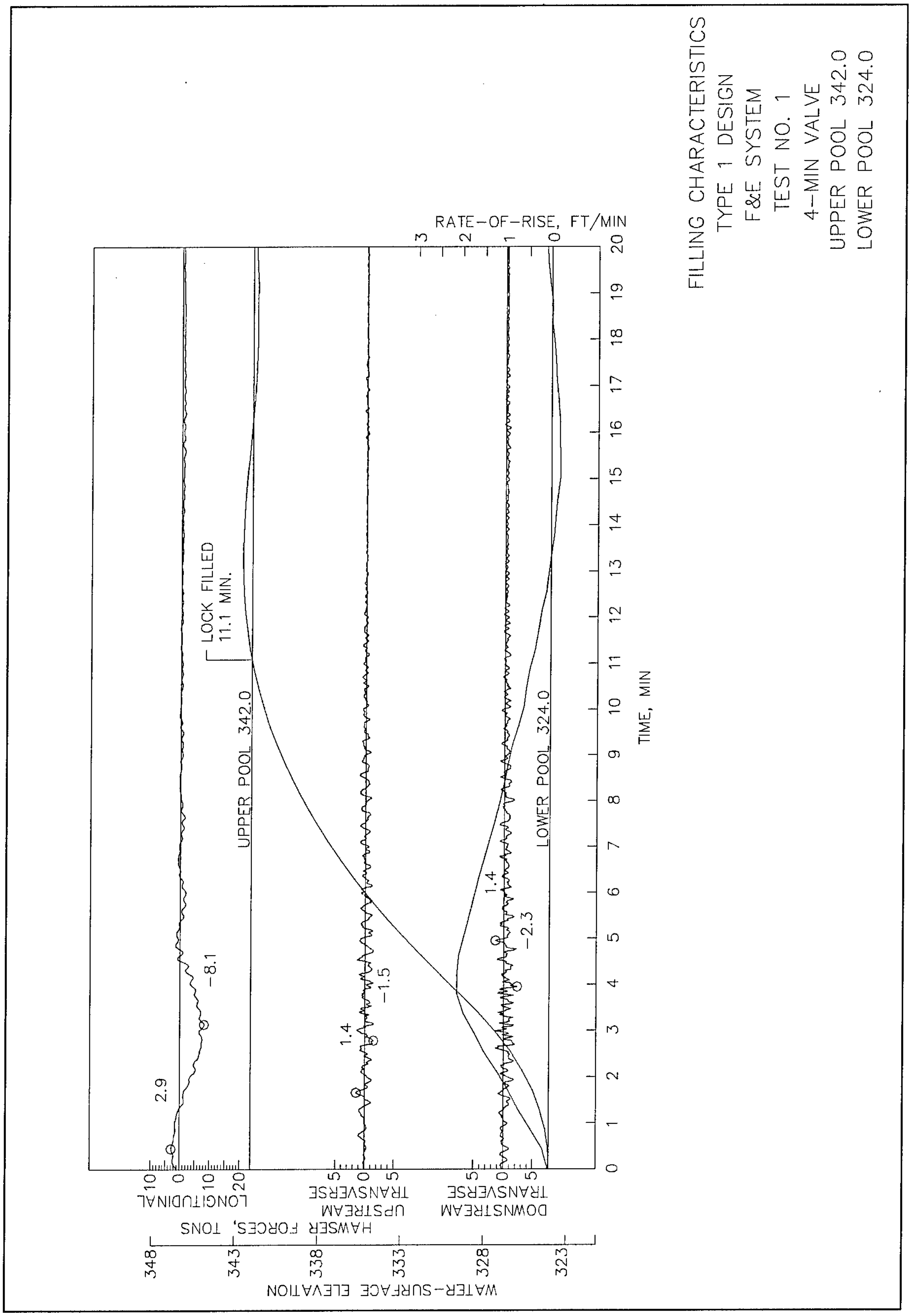
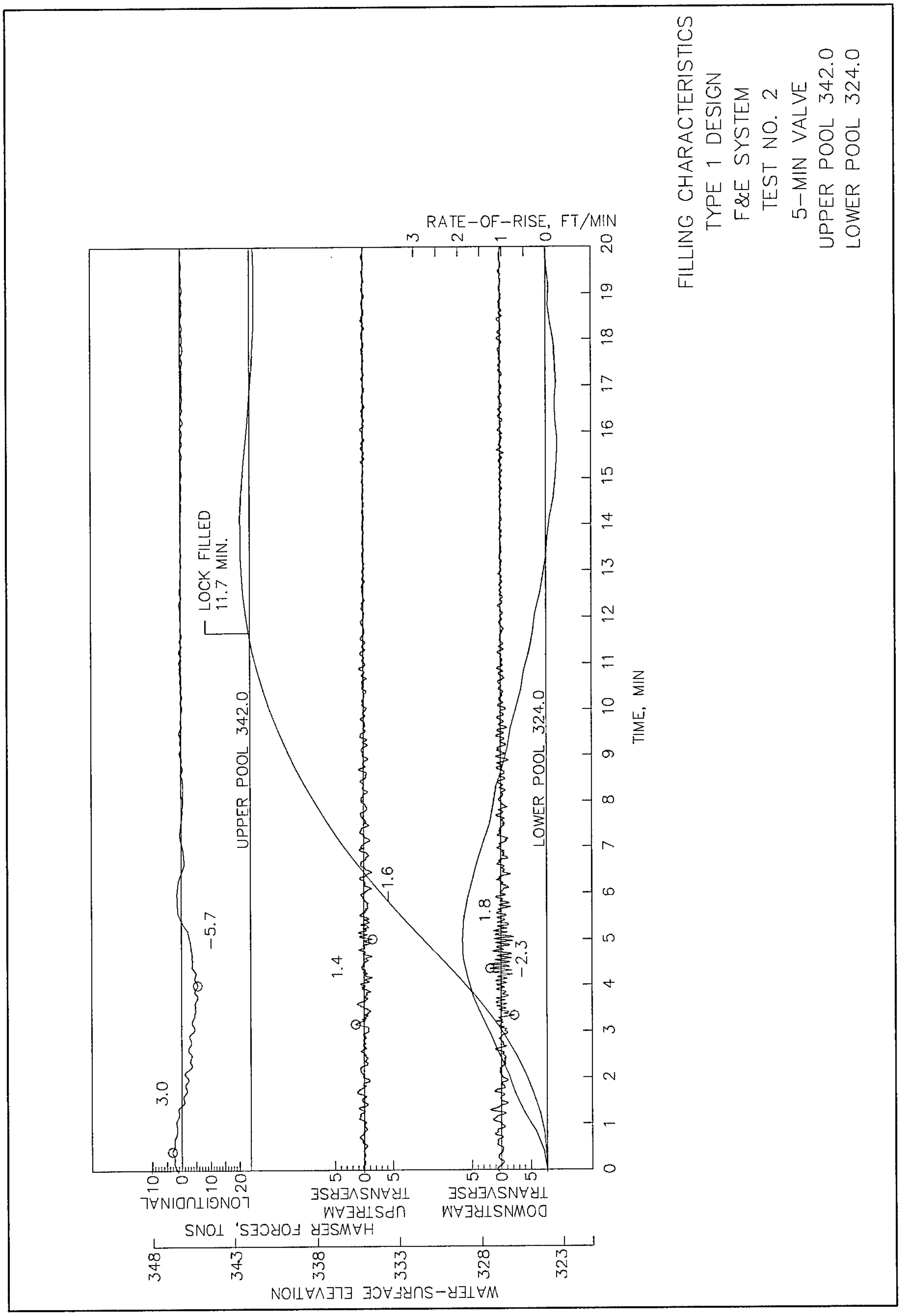

OUTLET AREA DETAILS
PARTIAL ELEVATION
PLAN VIEW OUTLET AREA
DIMENSIONS ARE IN FT
EL 308
EL 286
EL 303.8
EL 289
EL 305.8
EL 290.8
EL 308
EL 292.7
EL 313
EL 297
EL 313
EL 297
72.00
111.00
16.00
42.00
END DIFFUSER
STA. 16+14 D/S
R7.00
9.00
R2.50
S=0.0963
67.50
111.00
R2.50
16.91
END LAND
LOCK WALL
STA 15+03 D/S
1
6
15.87
STA 14+87.13 D/S
17.13
14.00
LOWER PINTLE
STA 14+70 D/S
39.00
LOCK WALL
STA 13+20 D/S
26.33
14.00

Plate 10

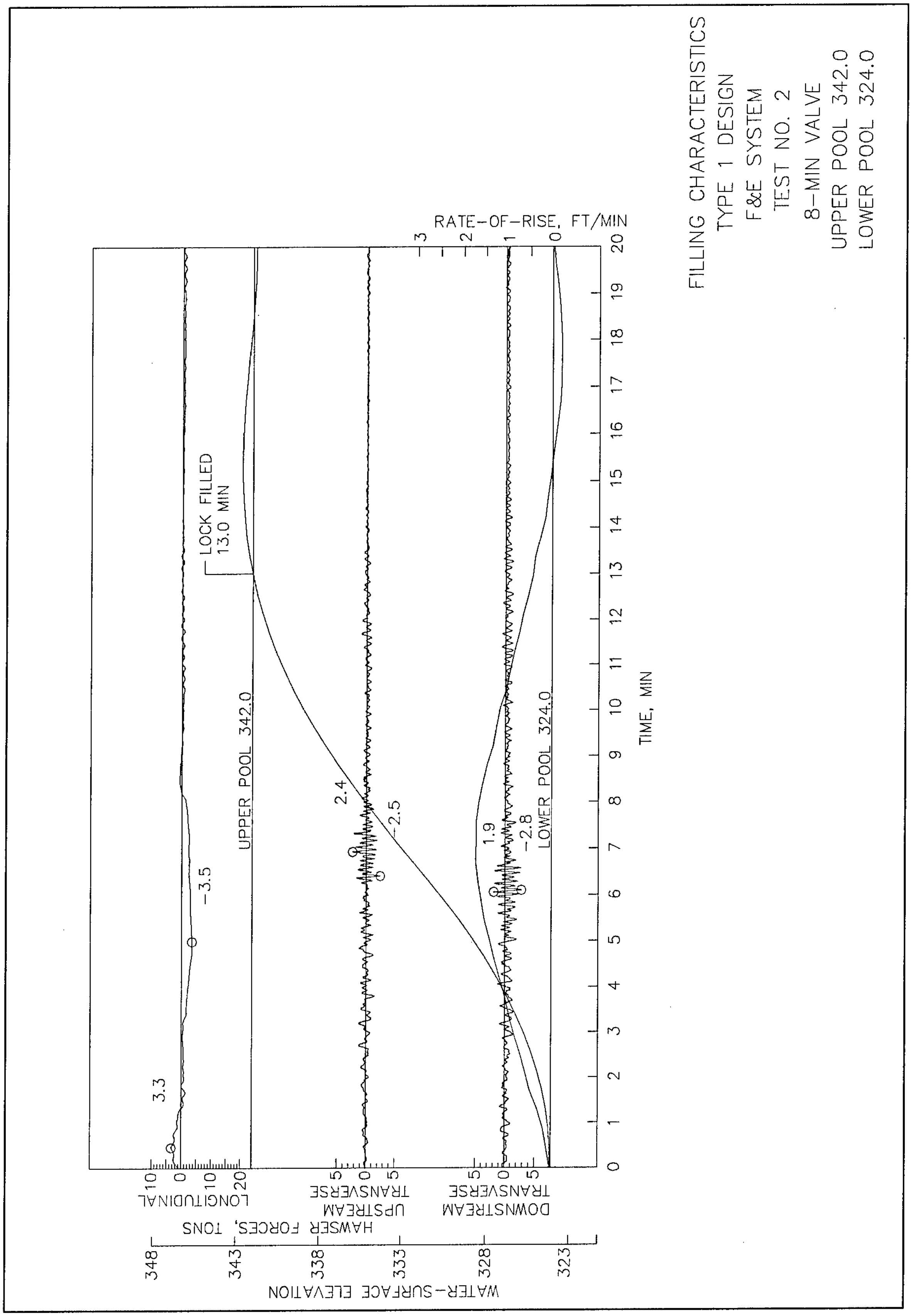


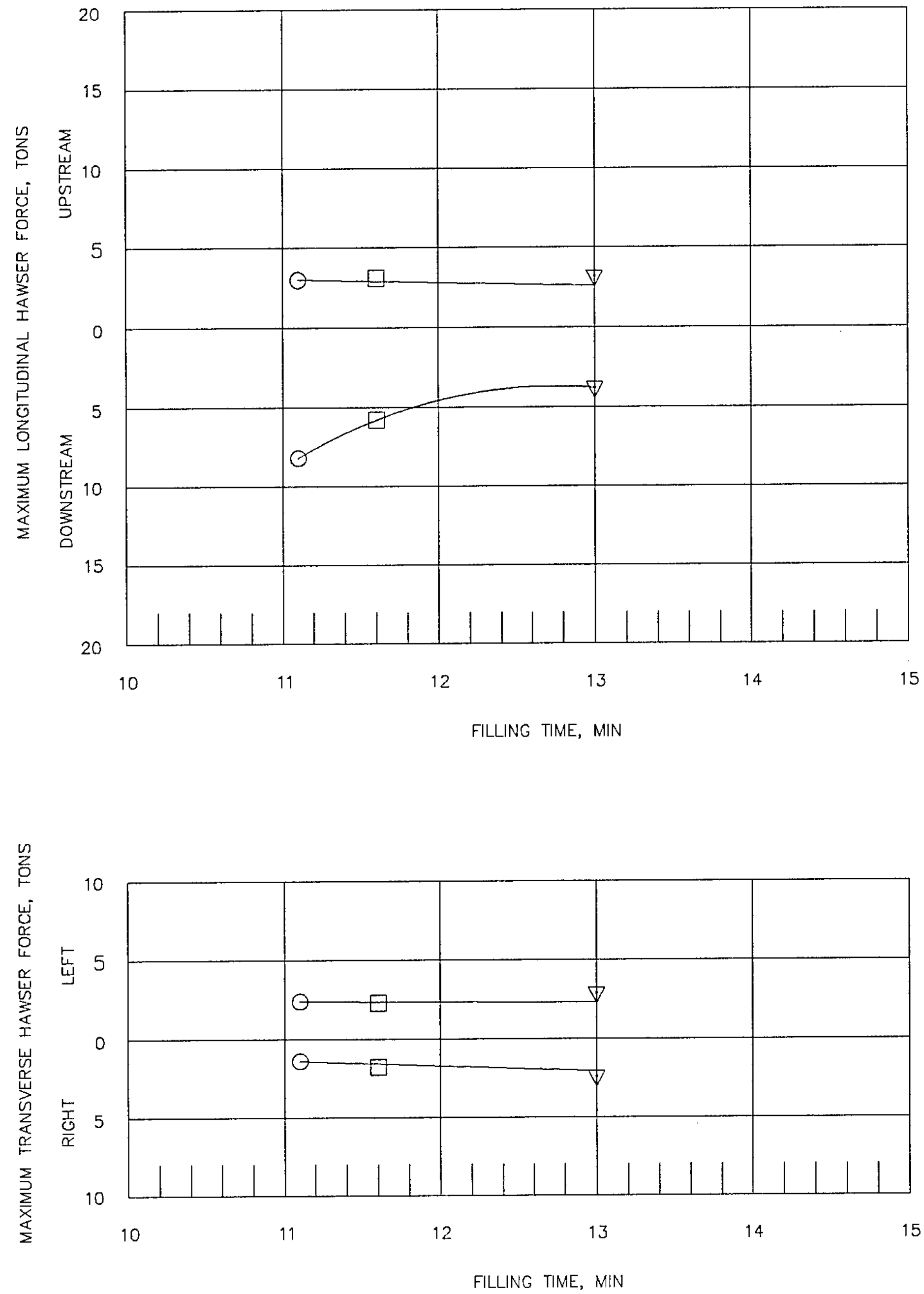
OUTLET DETAILS


FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 1
4-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
RATE-OF-RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
LOCK FILLED 11.1 MIN.
UPPER POOL 342.0
LOWER POOL 324.0
2.9
-8.1
1.4
-1.5
1.4
-2.3



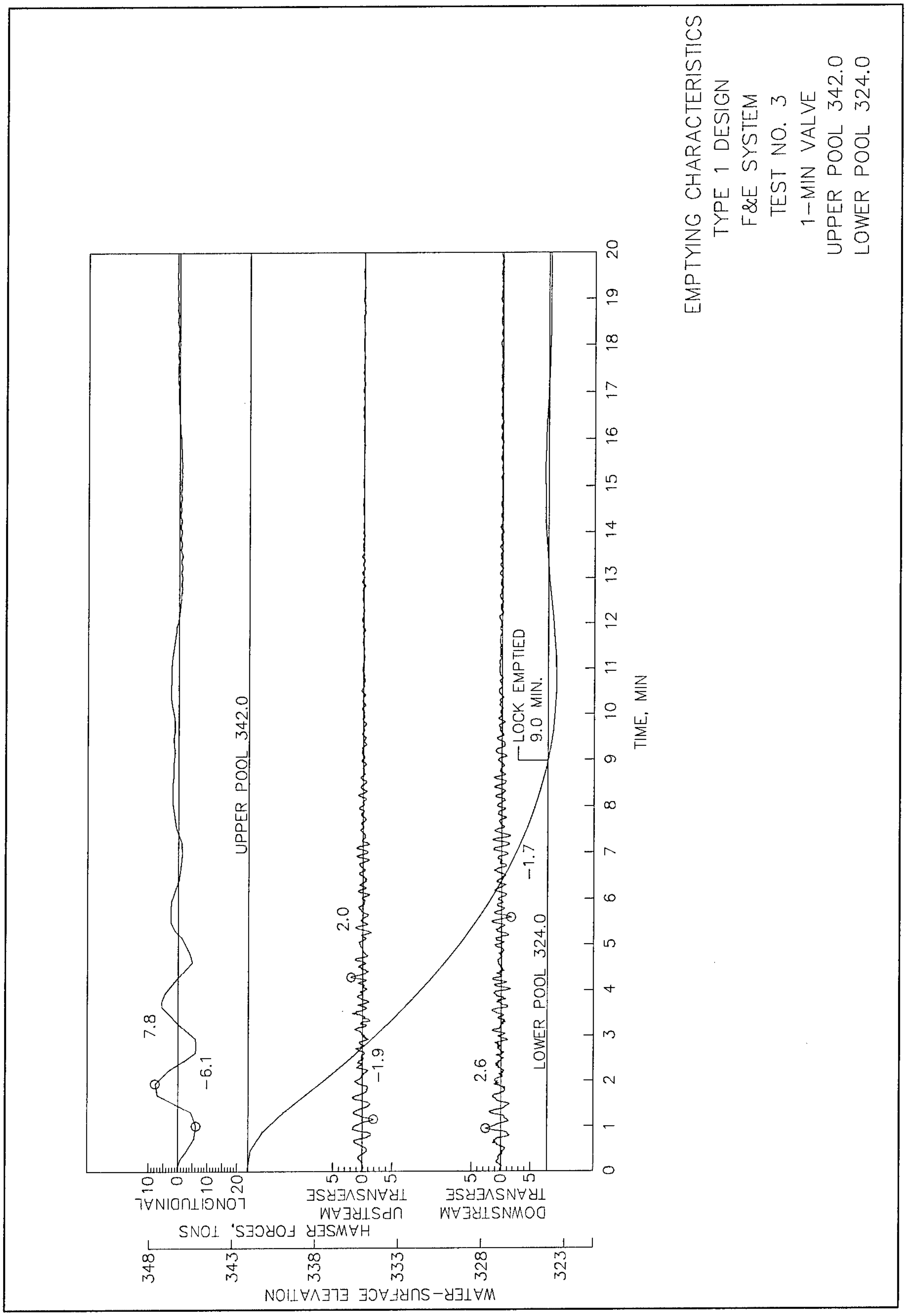
FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 2
5-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
RATE-OF-RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
LOCK FILLED 11.7 MIN.
UPPER POOL 342.0
LOWER POOL 324.0
3.0
-5.7
1.4
-1.6
1.8
-2.3

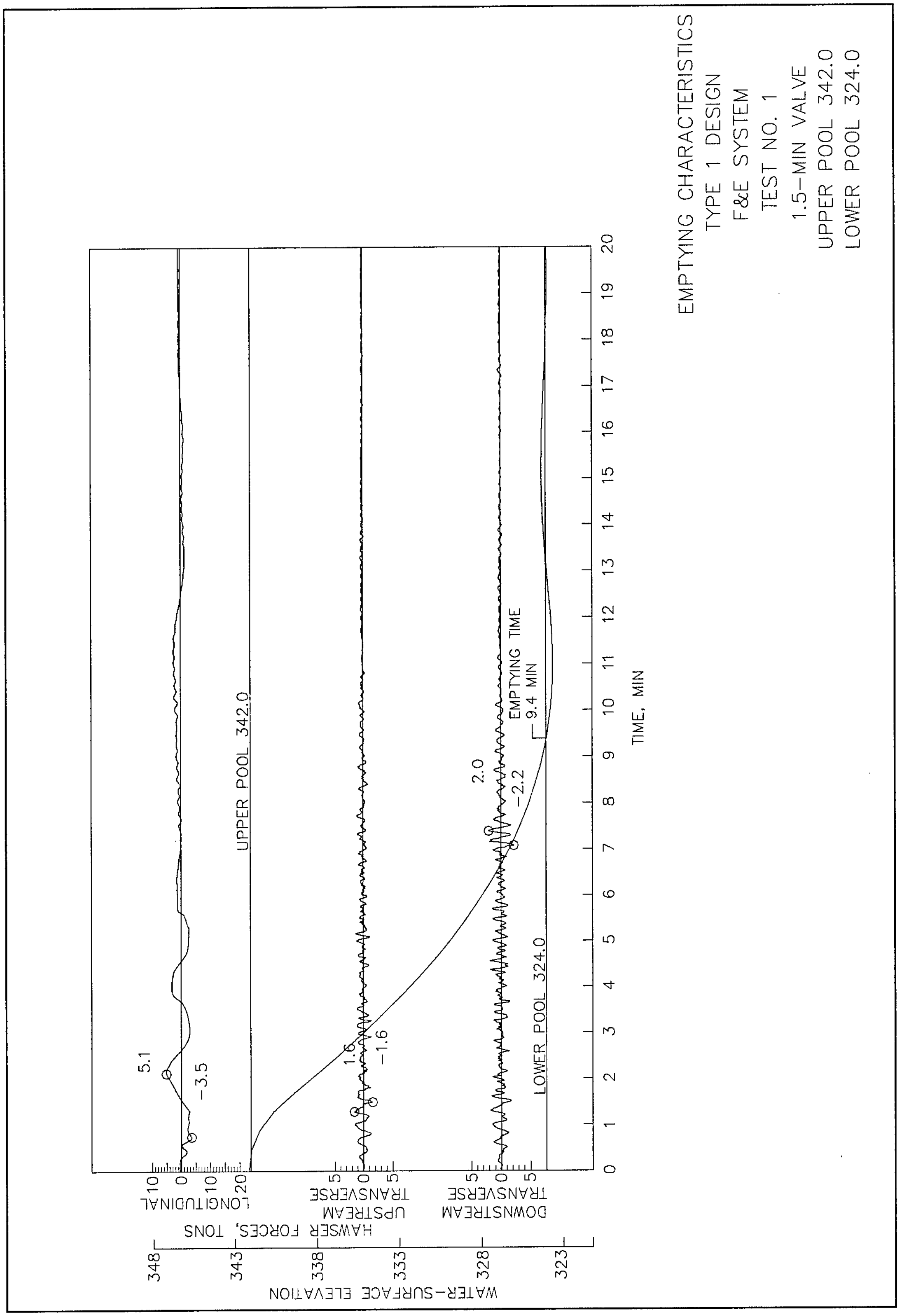

FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 2
8-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
RATE-OF-RISE, FT/MIN
TIME, MIN
LOCK FILLED 13.0 MIN
UPPER POOL 342.0
LOWER POOL 324.0
WATER-SURFACE ELEVATION
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
3.3
-3.5
2.4
-2.5
1.9
-2.8



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	4
□	5
▽	8

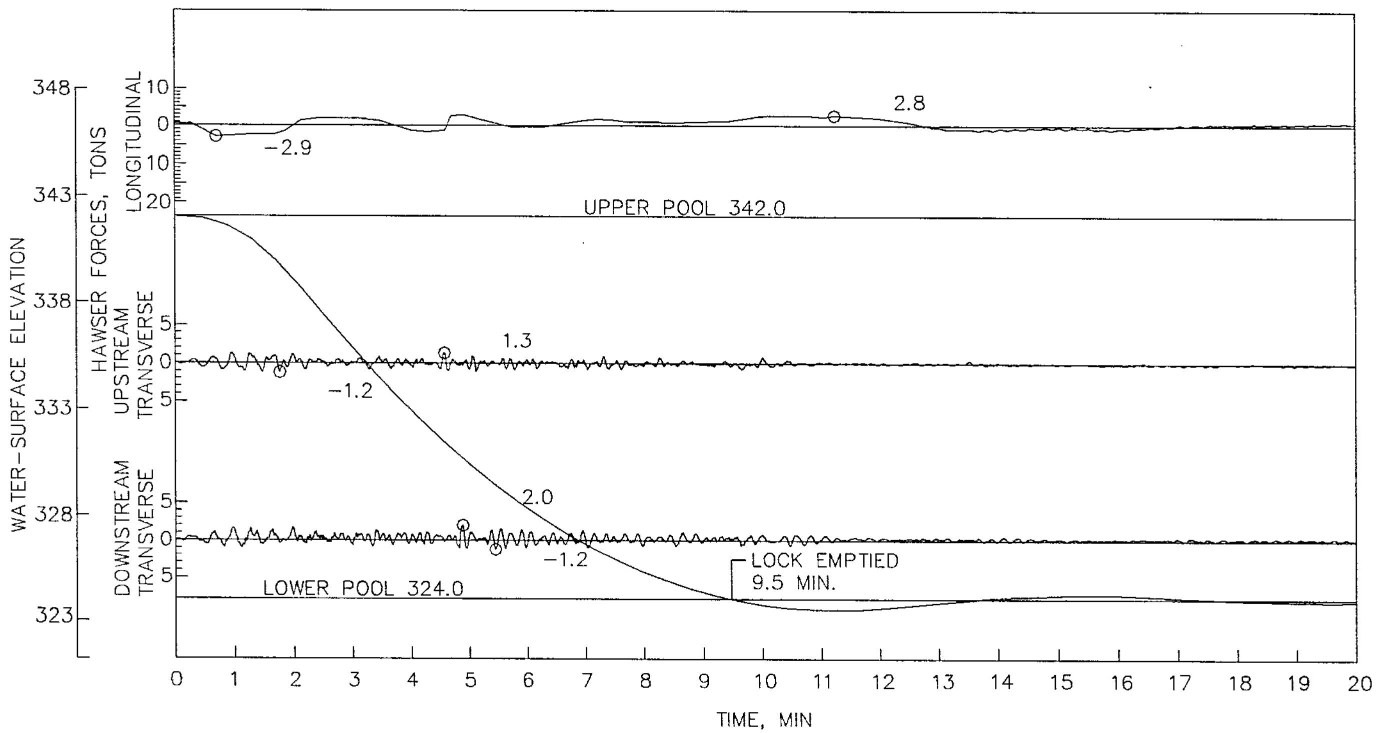
HAWSER FORCES
DURING FILLING
TYPE 1 DESIGN
F&E SYSTEM
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT


EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 3
1-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
UPPER POOL 342.0
LOWER POOL 324.0
LOCK EMPTIED 9.0 MIN.
7.8
-6.1
2.0
-1.9
2.6
-1.7
TIME, MIN
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
WATER-SURFACE ELEVATION

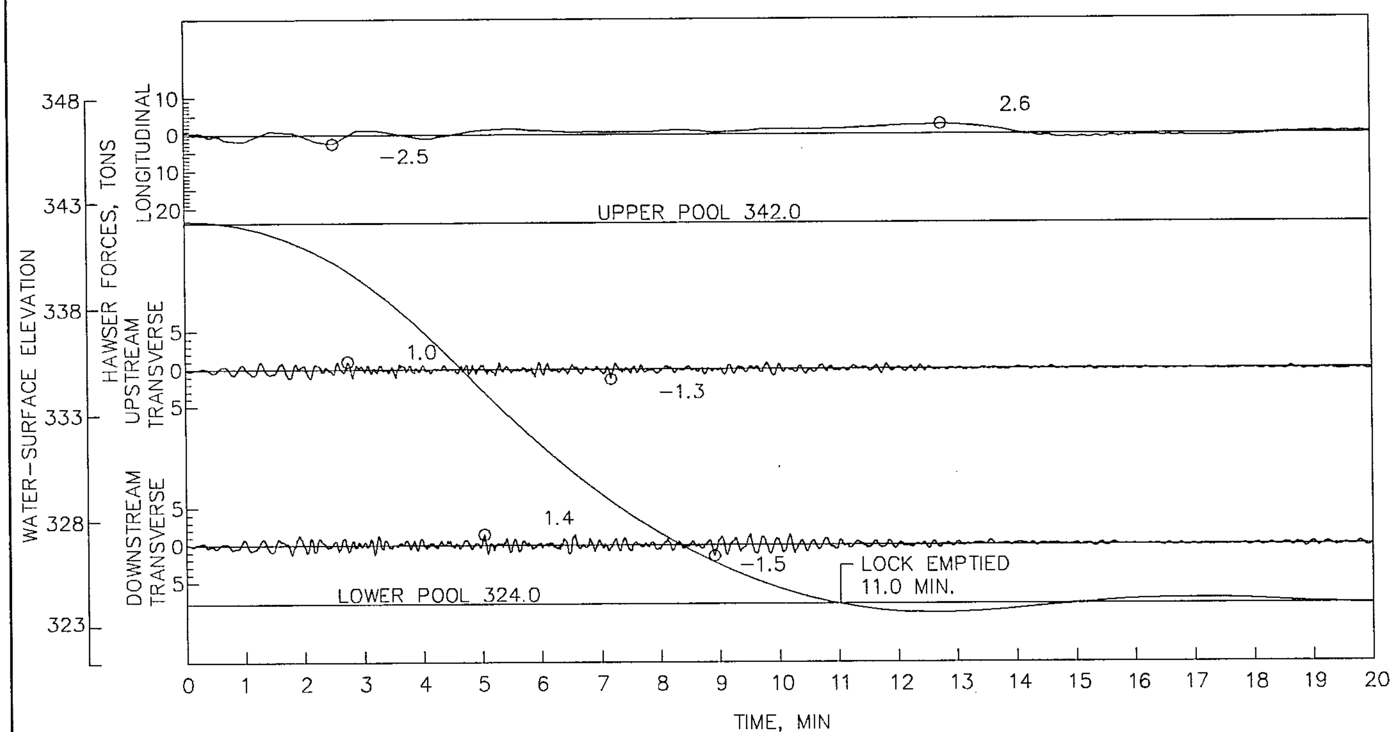


EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 1
1.5-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
WATER-SURFACE ELEVATION
348
343
338
333
328
323
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
10 0 10 20
5 0 5
5 0 5
UPPER POOL 342.0
LOWER POOL 324.0
5.1
-3.5
1.6
-1.6
2.0
-2.2
EMPTYING TIME
9.4 MIN
TIME, MIN
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

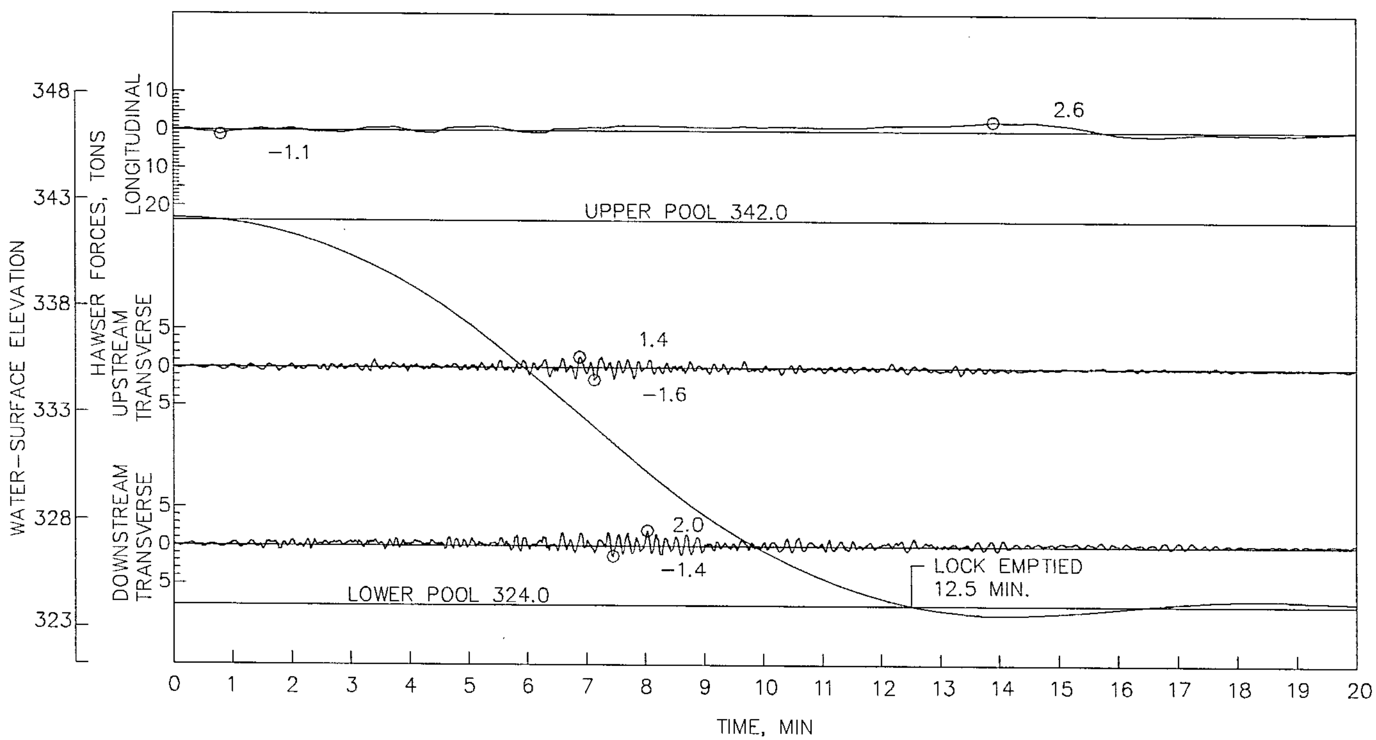
Plate 18



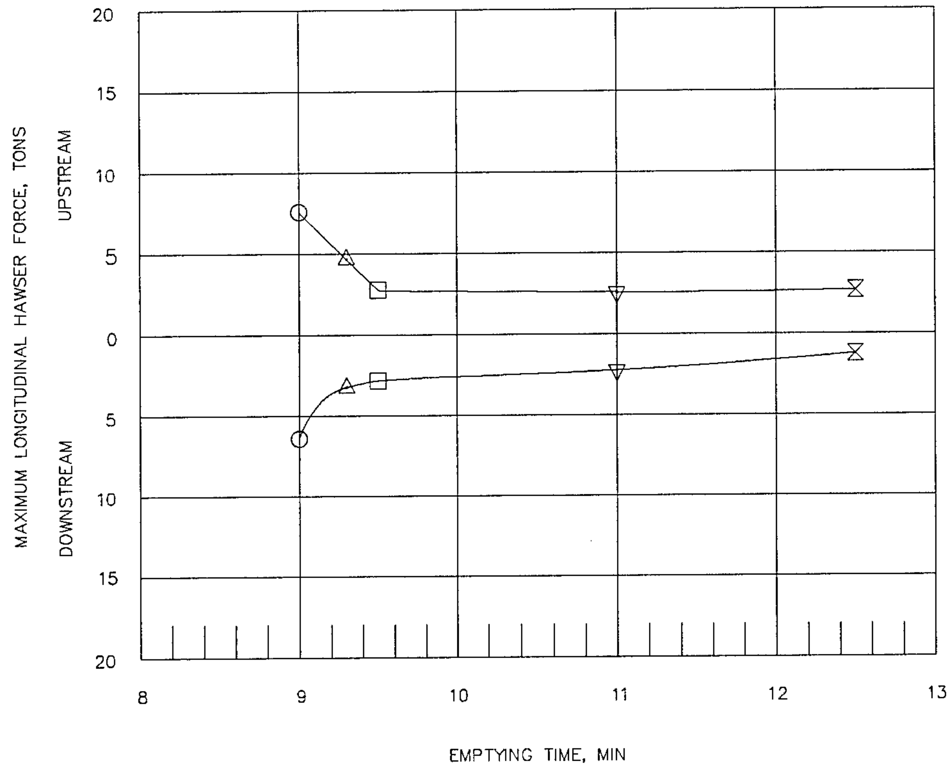
EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 1
2-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0

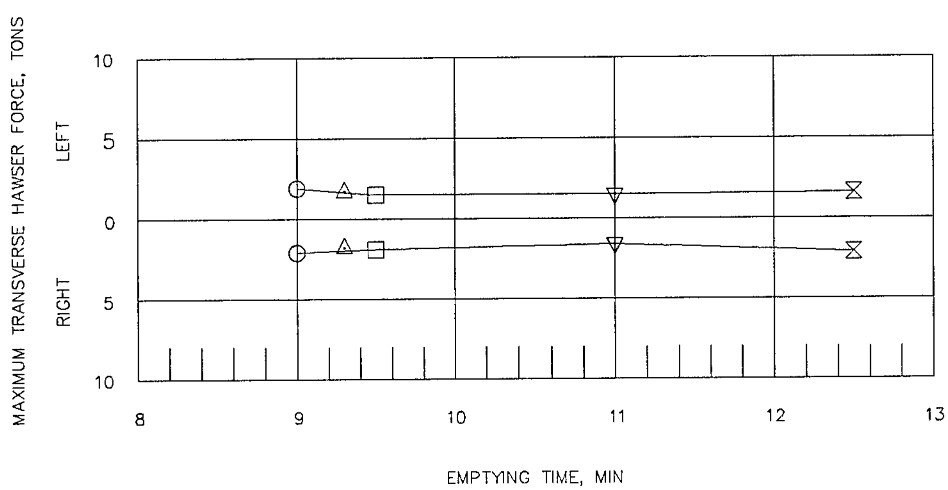


EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 3
5-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0



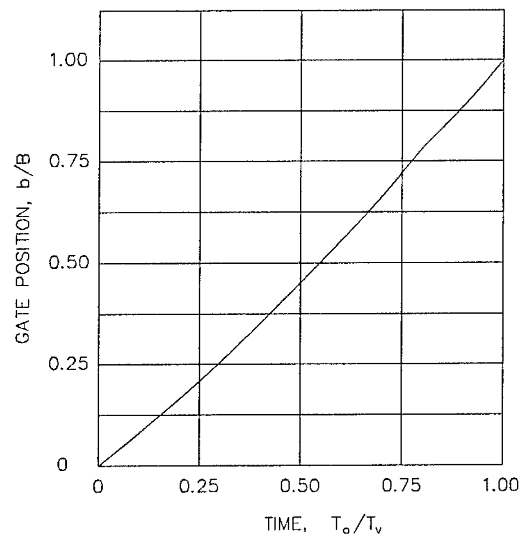
EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
TEST NO. 3
8-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	1.5
□	2
▽	5
⧖	8

HAWSER FORCES
DURING EMPTYING
TYPE 1 DESIGN
F&E SYSTEM
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT

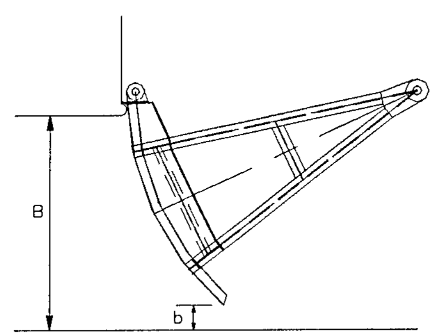


T_o = TIME SINCE OPENING BEGAN

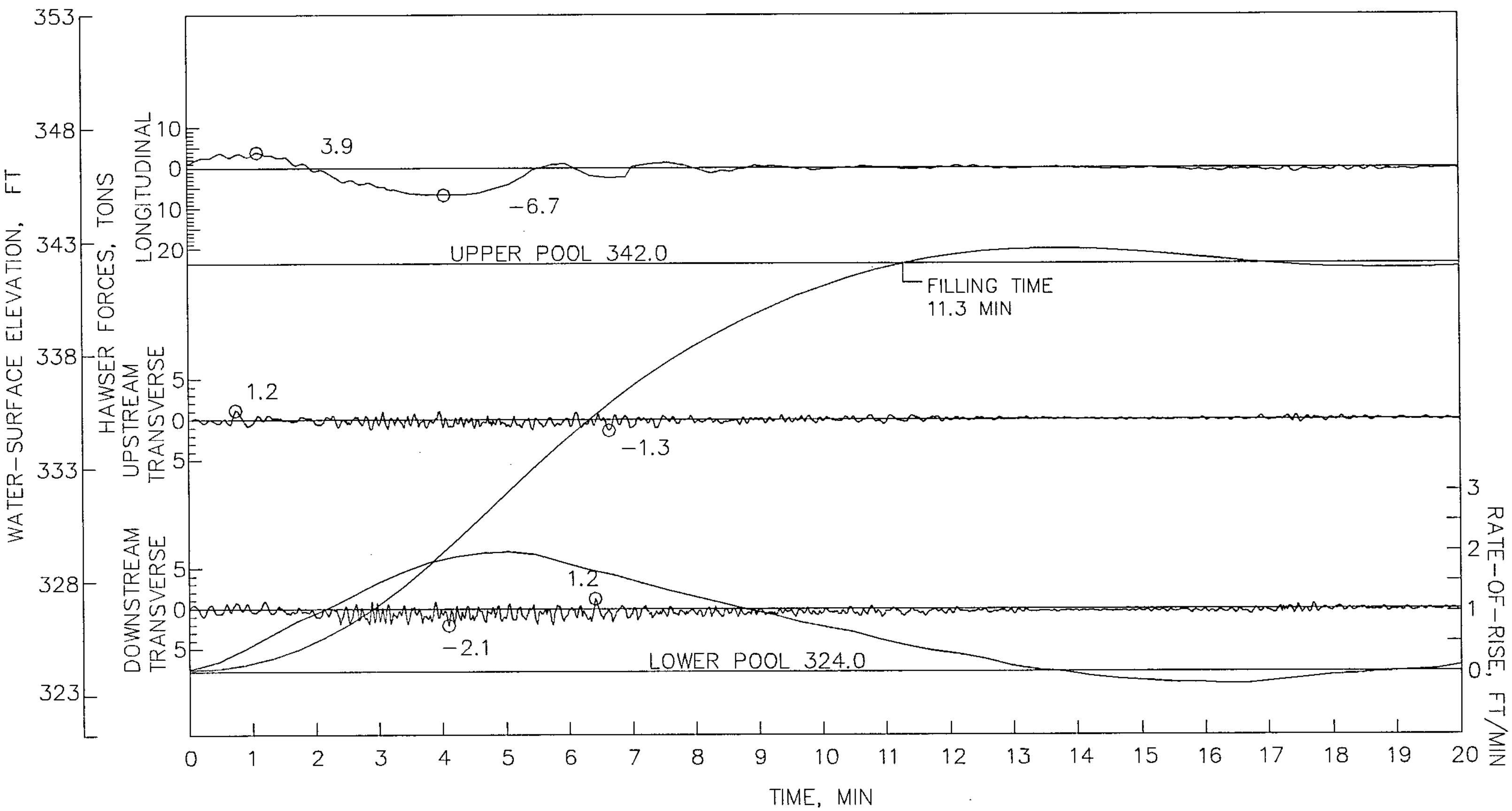
T_v = TIME TO OPEN FULL

B = 16 FT
b = VERTICAL DIST. FROM LIP TO FLOOR

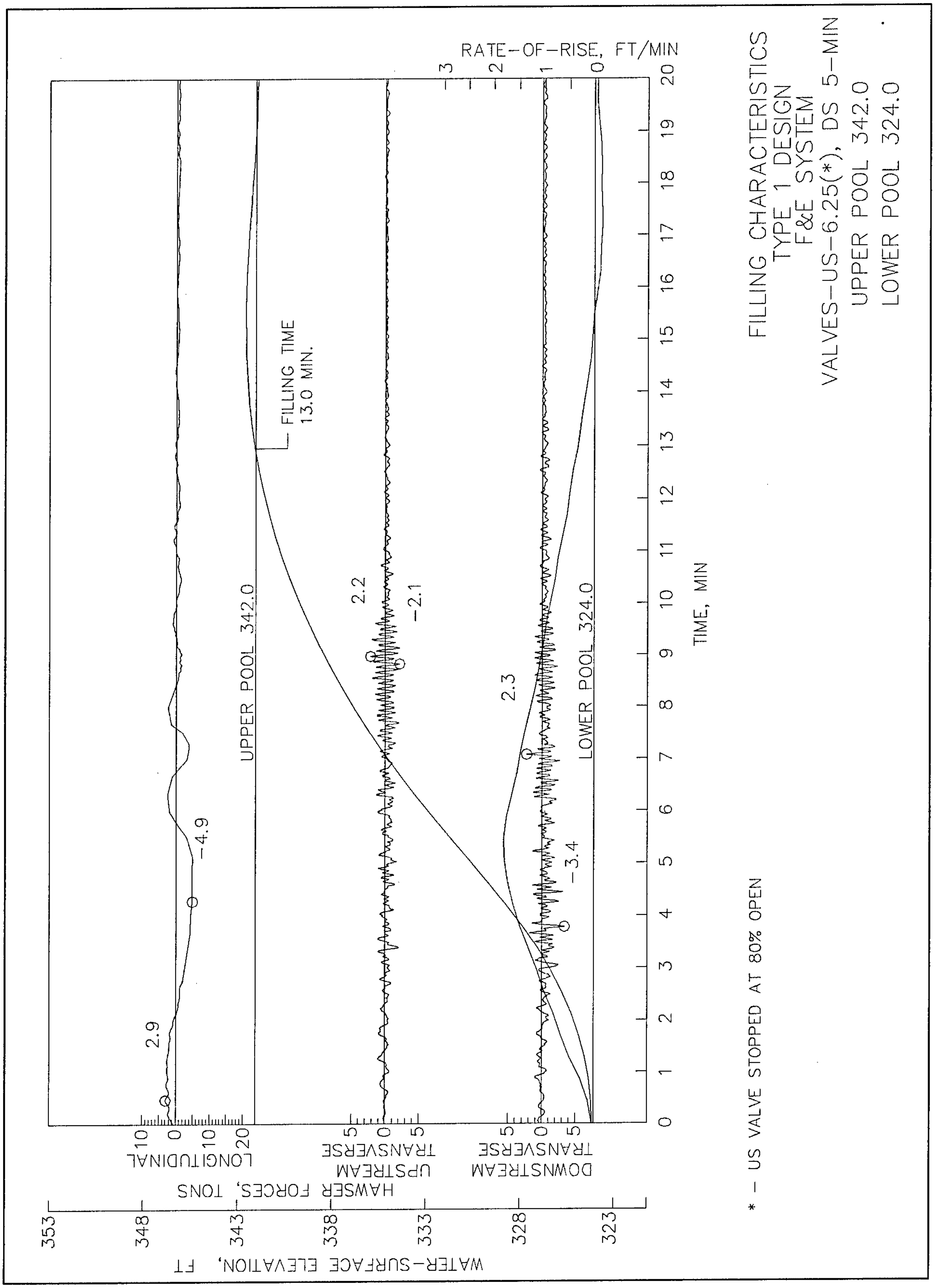
b/B	T_o/T_v
0	0
0.080	0.10
0.164	0.20
0.255	0.30
0.352	0.40
0.452	0.50
0.556	0.60
0.664	0.70
0.781	0.80
0.886	0.90
1.000	1.00

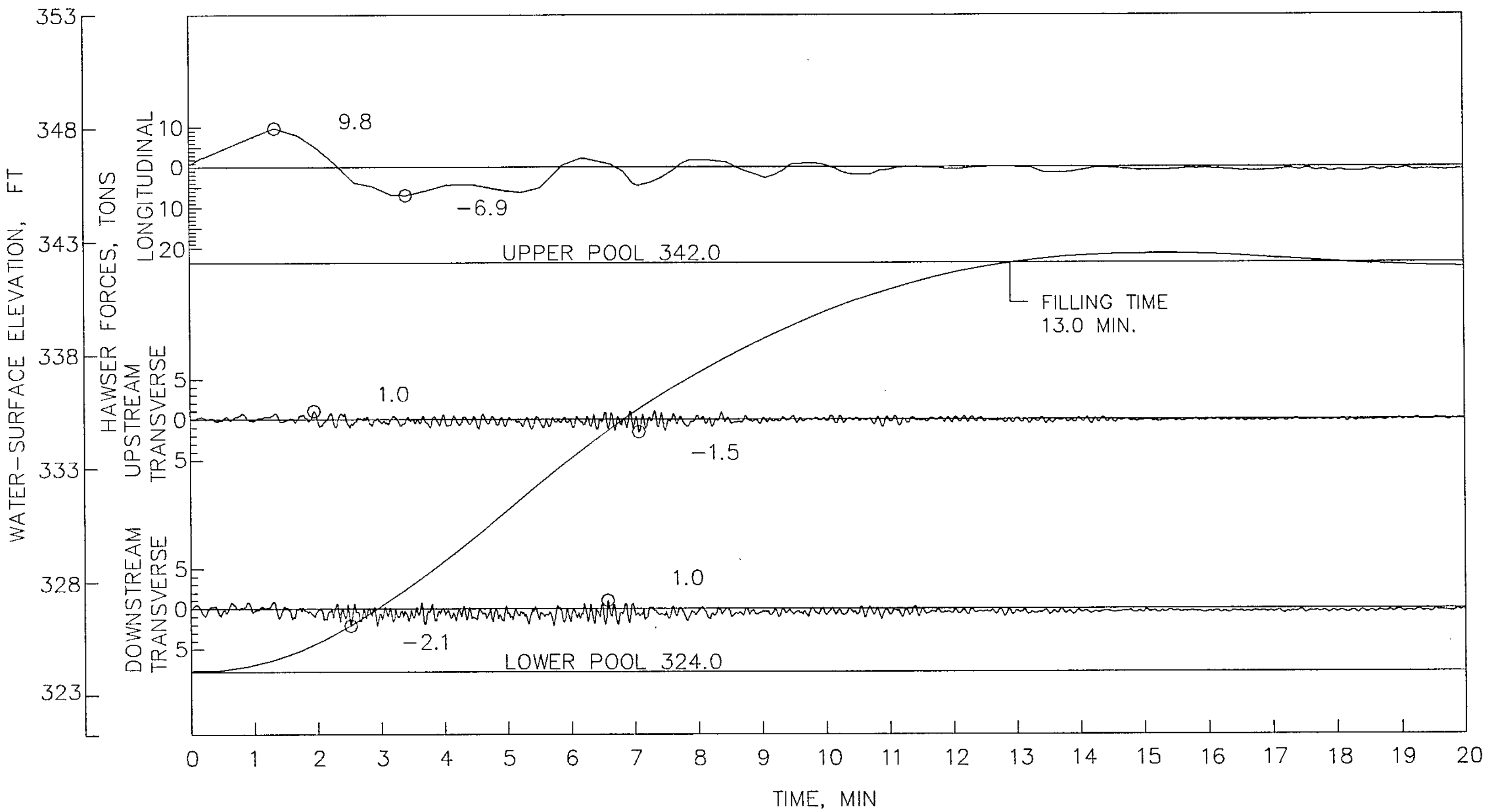


TYPE 1 DESIGN
CONSTANT SPEED
VALVE OPENING CURVE



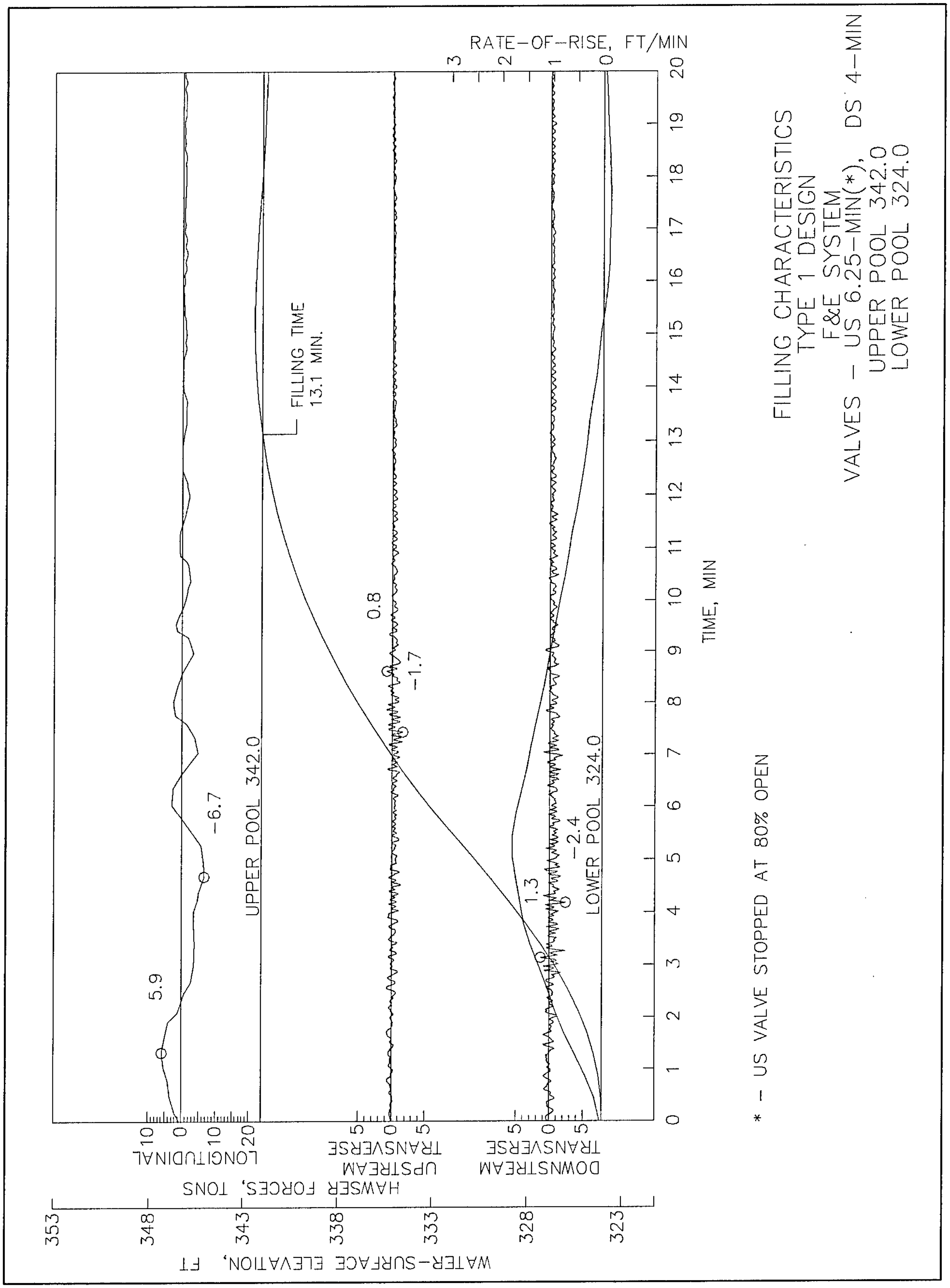
FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
VALVES–U/S 5–MIN, D/S 4–MIN
UPPER POOL 342.0
LOWER POOL 324.0

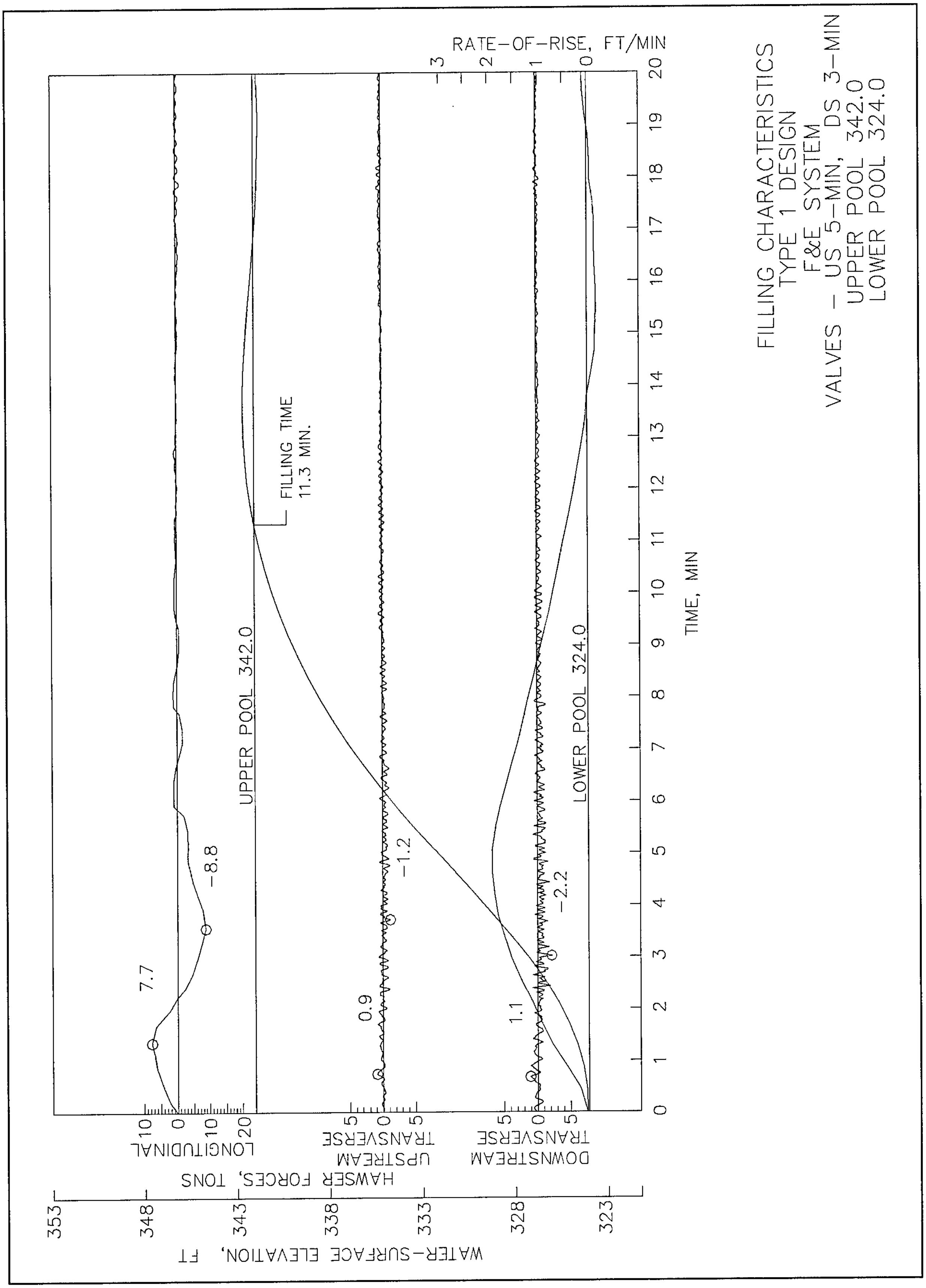

FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
VALVES-US-6.25(*), DS 5-MIN
UPPER POOL 342.0
LOWER POOL 324.0
* - US VALVE STOPPED AT 80% OPEN
RATE-OF-RISE, FT/MIN
TIME, MIN
FILLING TIME
13.0 MIN.
UPPER POOL 342.0
LOWER POOL 324.0
WATER-SURFACE ELEVATION, FT
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM
TRANSVERSE
DOWNSTREAM
TRANSVERSE
2.9
-4.9
2.2
-2.1
2.3
-3.4

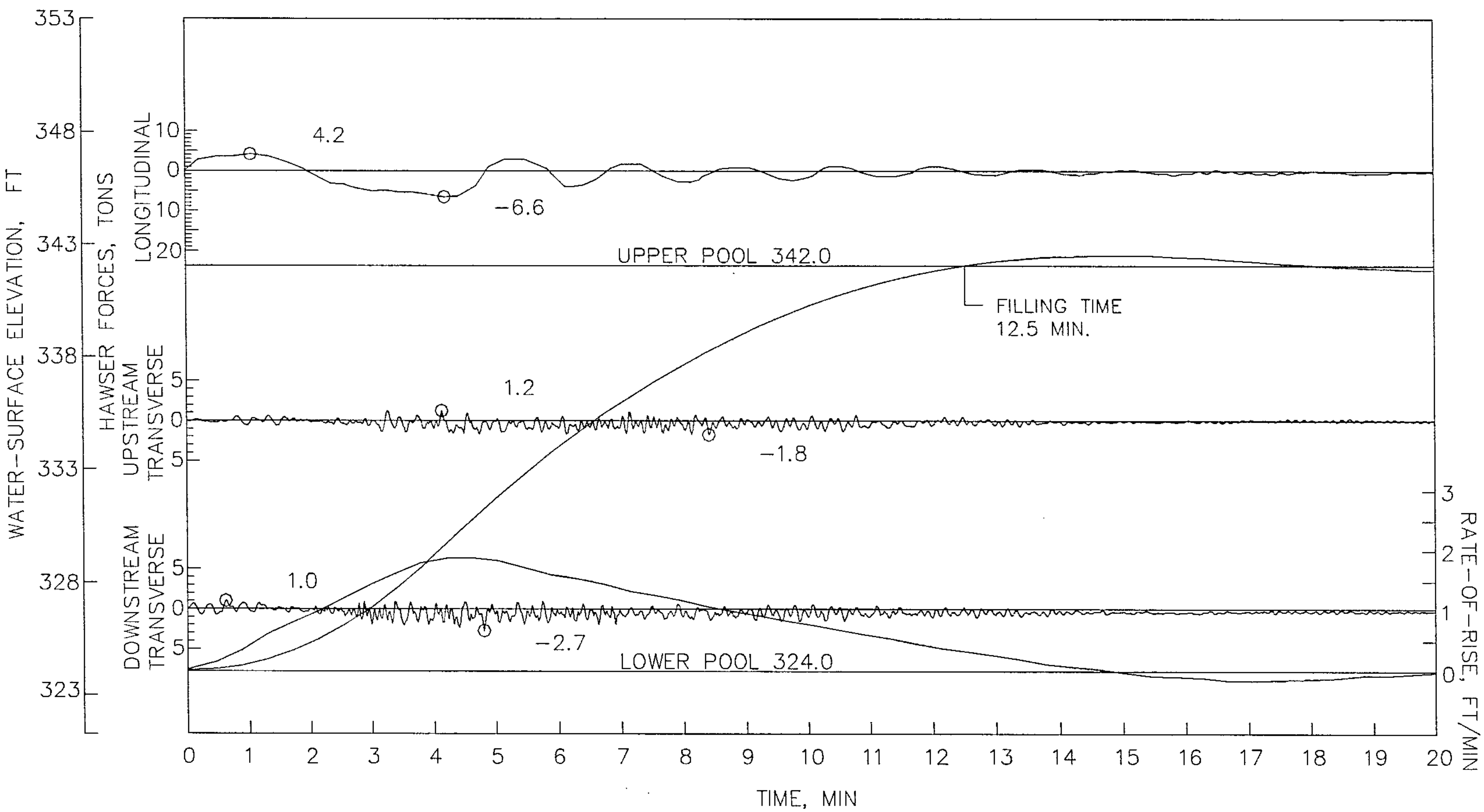


* – US VALVE STOPPED AT 80% OPEN

FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
VALVES – US 6.25-MIN(*), DS 3-MIN
UPPER POOL 342.0
LOWER POOL 324.0

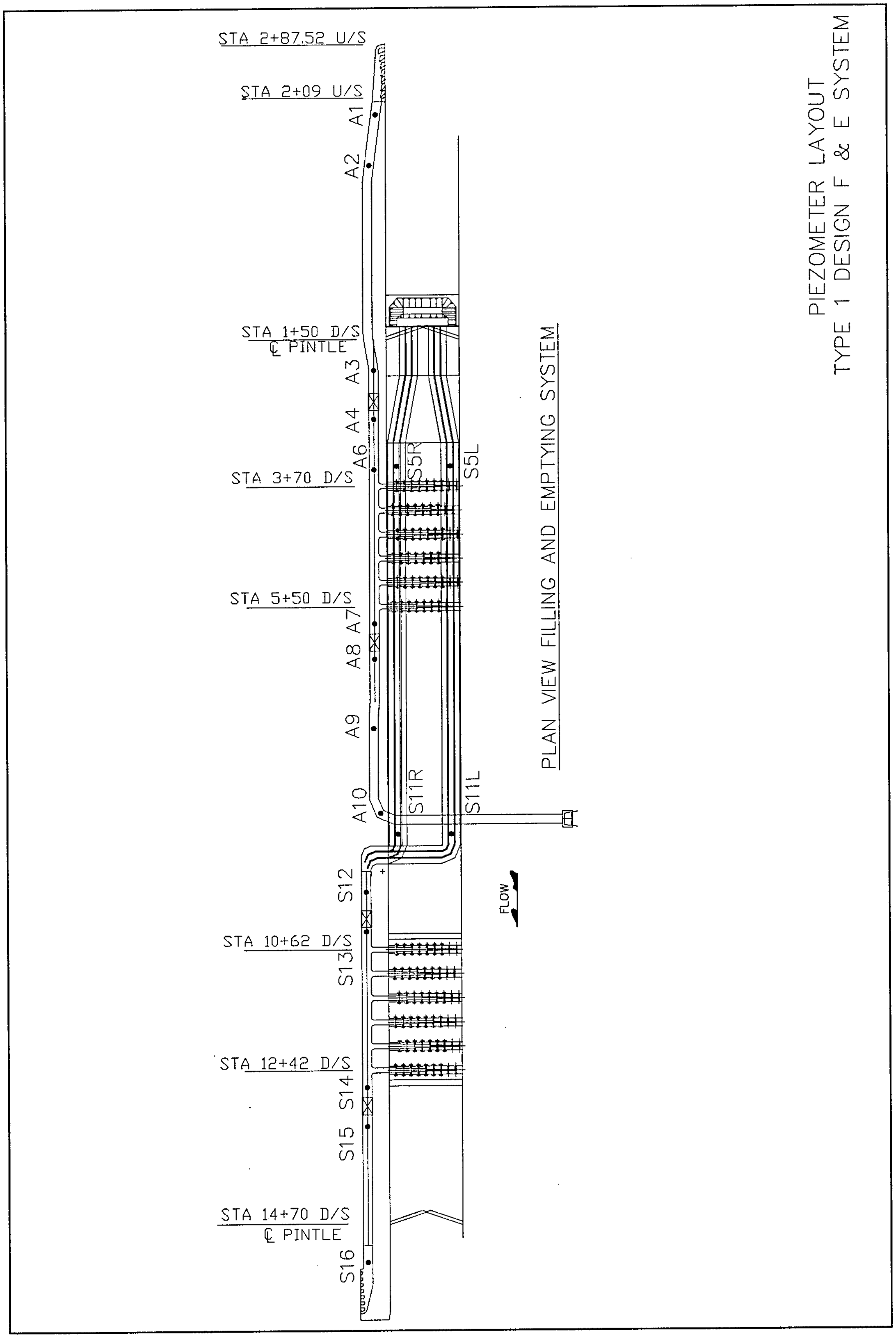

FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
VALVES - US 6.25-MIN(*), DS 4-MIN
UPPER POOL 342.0
LOWER POOL 324.0
* - US VALVE STOPPED AT 80% OPEN
RATE-OF-RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
UPPER POOL 342.0
LOWER POOL 324.0
FILLING TIME 13.1 MIN.
5.9
-6.7
0.8
-1.7
1.3
-2.4


FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
VALVES - US 5-MIN, DS 3-MIN
UPPER POOL 342.0
LOWER POOL 324.0
RATE-OF-RISE, FT/MIN
TIME, MIN
FILLING TIME
11.3 MIN.
UPPER POOL 342.0
LOWER POOL 324.0
WATER-SURFACE ELEVATION, FT
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
7.7
-8.8
0.9
-1.2
1.1
-2.2

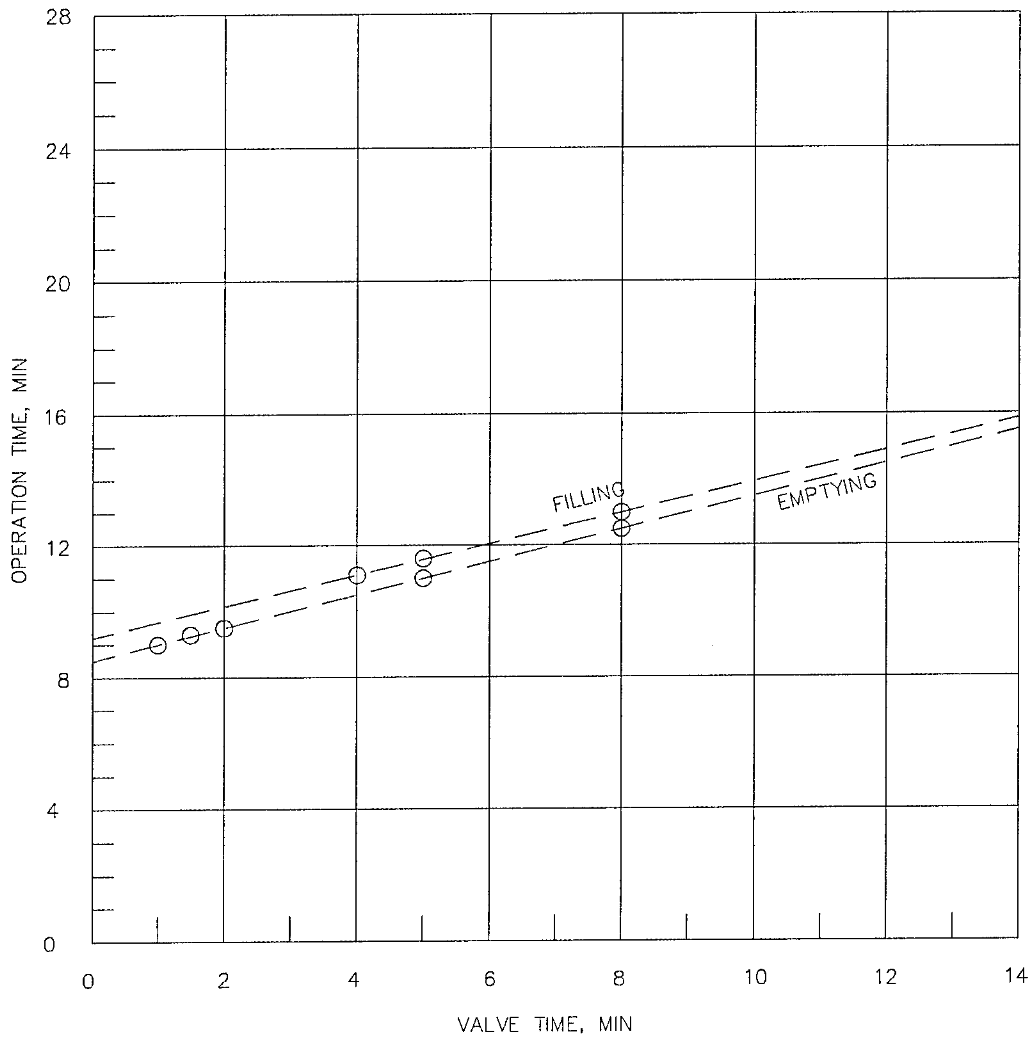


* – US VALVE STOPPED AT 80% OPEN

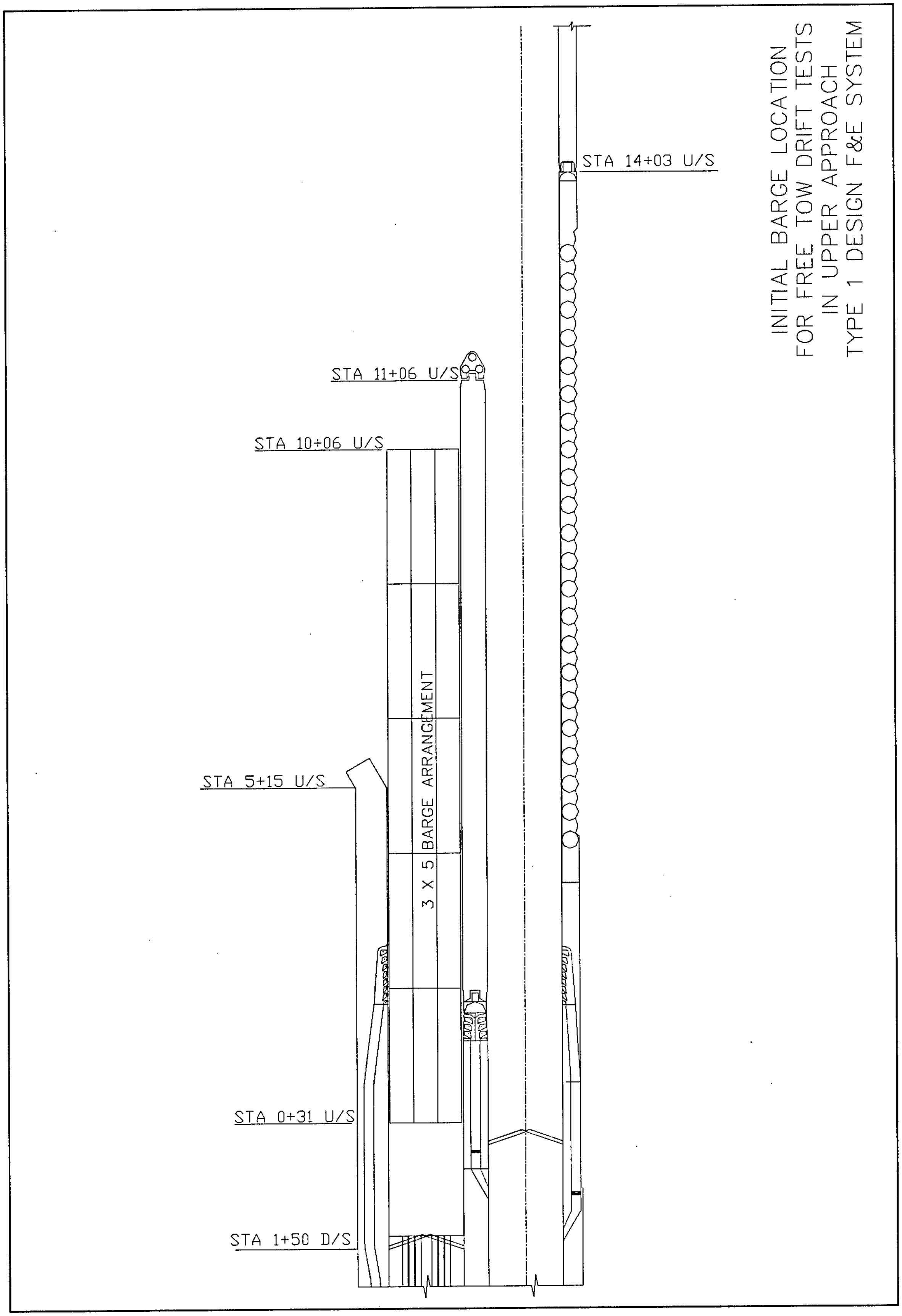
FILLING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
VALVES – US 5-MIN(*), DS 4-MIN
UPPER POOL 342.0
LOWER POOL 324.0

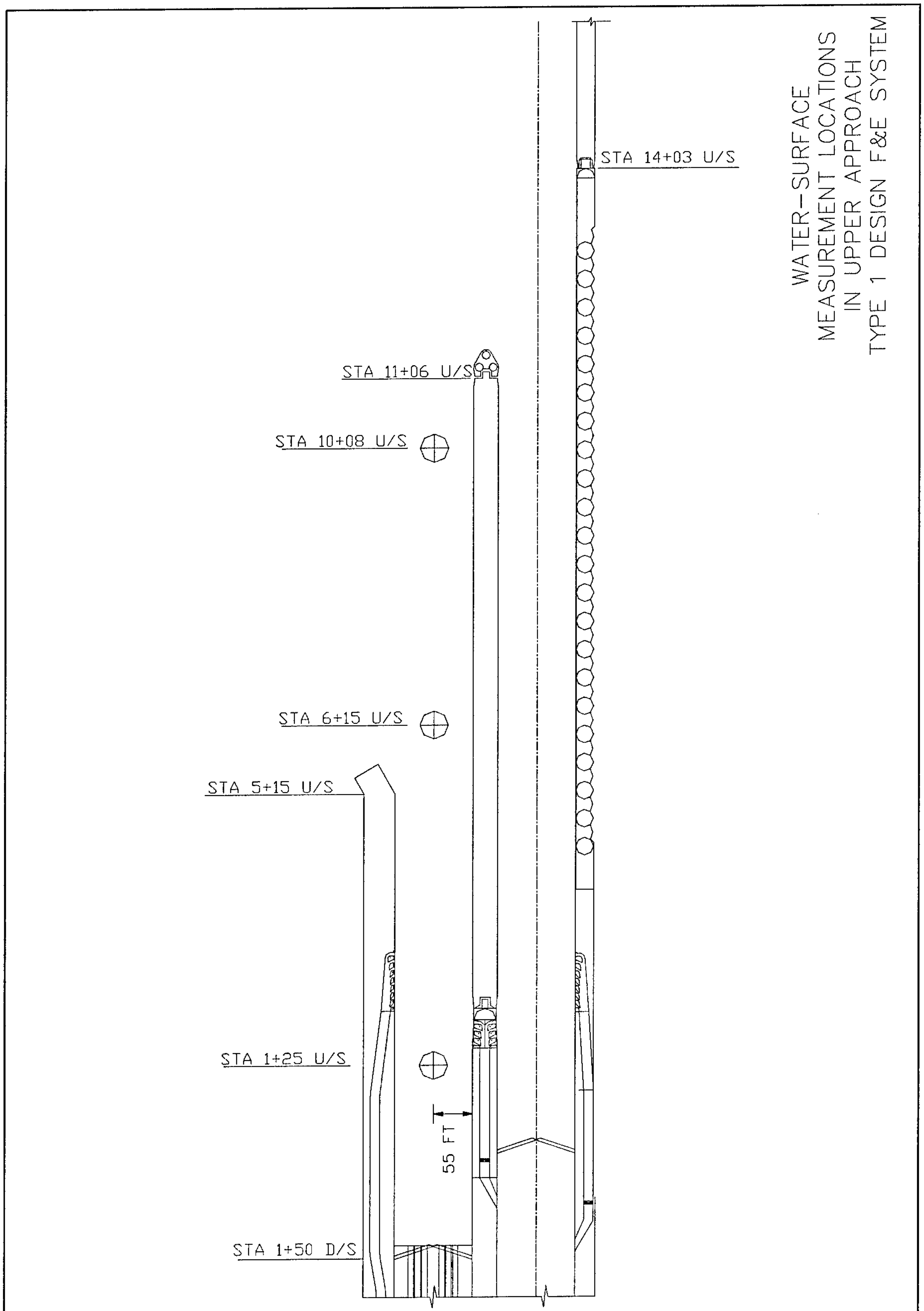


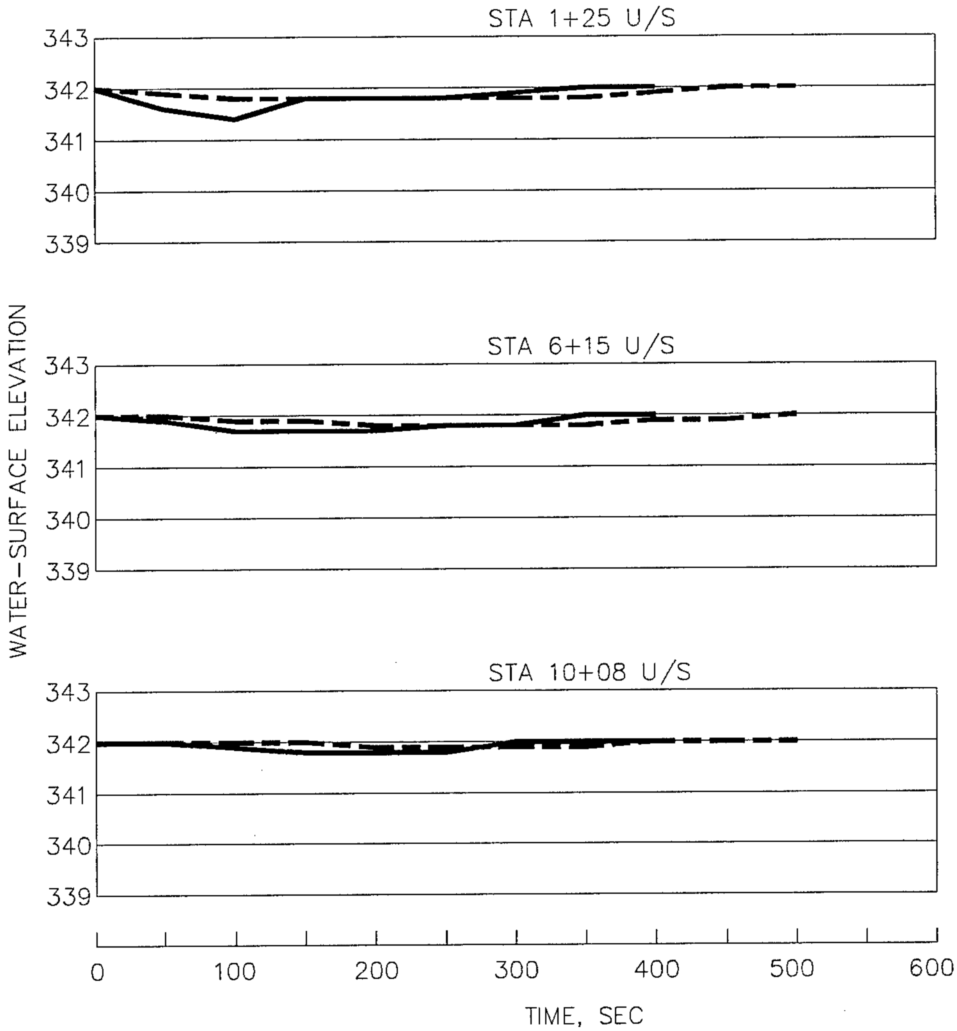
PIEZOMETER LAYOUT
TYPE 1 DESIGN F & E SYSTEM



OPERATION TIMES FOR
TYPE 1 DESIGN F&E SYSTEM
18-FT LIFT
UPPER POOL EL 342.0
LOWER POOL EL 324.0


INITIAL BARGE LOCATION
FOR FREE TOW DRIFT TESTS
IN UPPER APPROACH
TYPE 1 DESIGN F&E SYSTEM
STA 14+03 U/S
STA 11+06 U/S
STA 10+06 U/S
3 X 5 BARGE ARRANGEMENT
STA 5+15 U/S
STA 0+31 U/S
STA 1+50 D/S

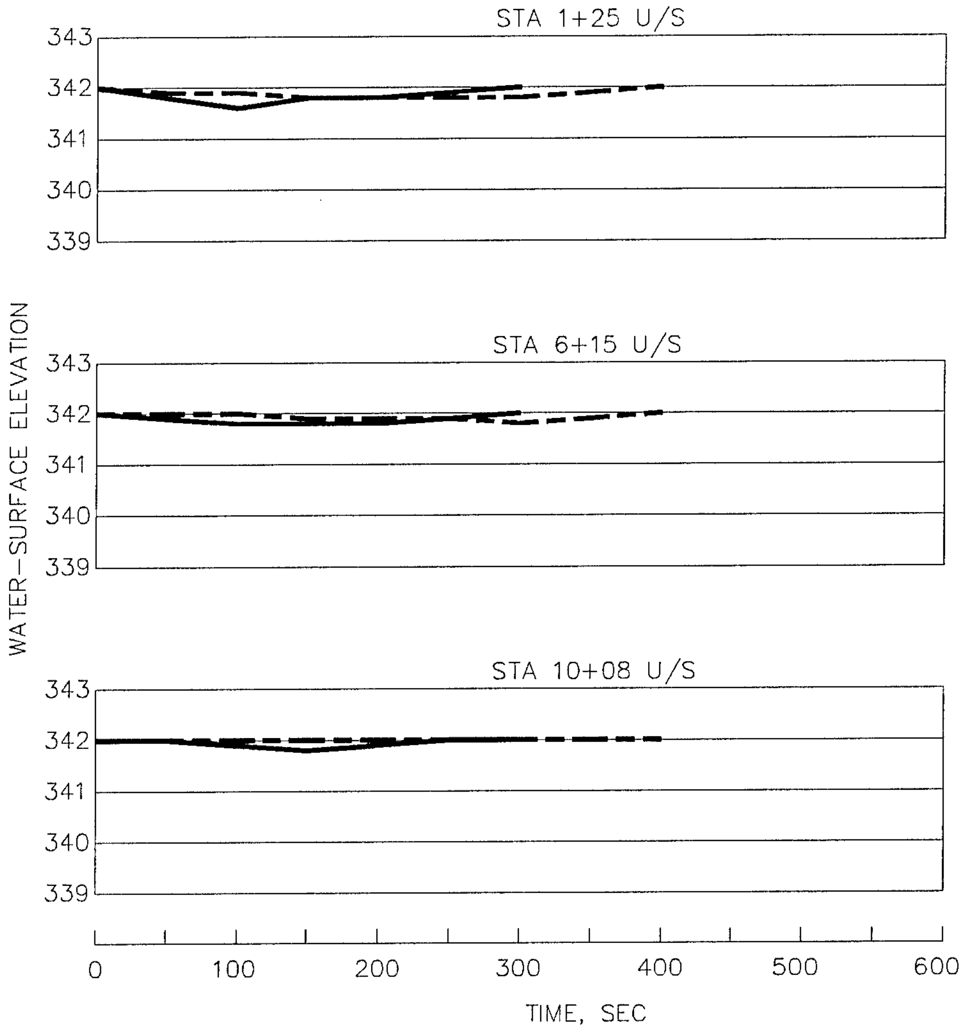

WATER-SURFACE
MEASUREMENT LOCATIONS
IN UPPER APPROACH
TYPE 1 DESIGN F&E SYSTEM
STA 14+03 U/S
STA 11+06 U/S
STA 10+08 U/S
STA 6+15 U/S
STA 5+15 U/S
STA 1+25 U/S
55 FT
STA 1+50 D/S



NOTE: WATER-SURFACE MEASURED 55 FT LANDWARD FROM RIVERSIDE APPROACH WALL OF LANDSIDE LOCK

——— 2 MIN FILLING VALVES
– – – – 5 MIN FILLING VALVES

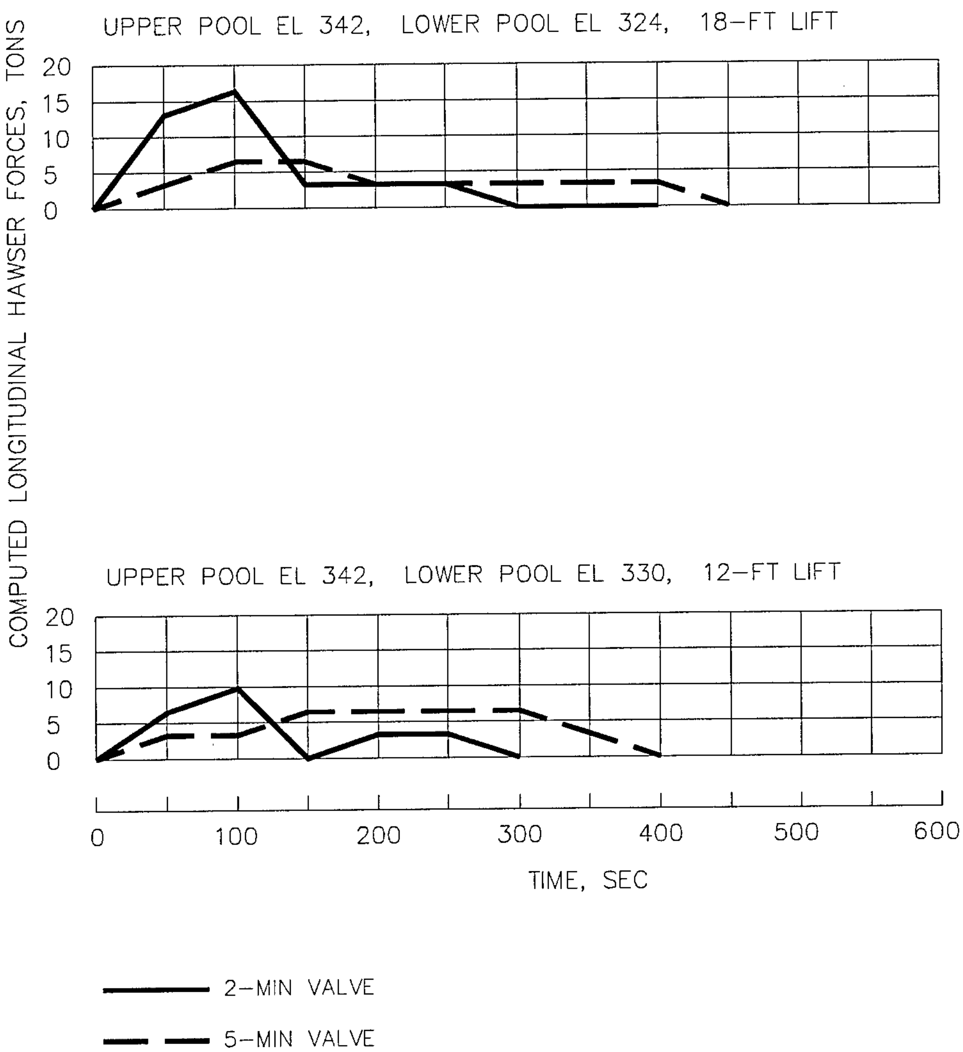
WATER-SURFACE ELEVATIONS
IN UPPER APPROACH
TYPE 1 DESIGN F&E SYSTEM
UPPER POOL EL 342.0
LOWER POOL EL 324.0



NOTE: WATER-SURFACE MEASURED 55 FT LANDWARD FROM RIVERSIDE APPROACH WALL OF LANDSIDE LOCK

——— 2 MIN FILLING VALVES
– – – – – 5 MIN FILLING VALVES

WATER-SURFACE ELEVATIONS
IN UPPER APPROACH
TYPE 1 DESIGN F&E SYSTEM
UPPER POOL EL 342.0
LOWER POOL EL 330.0



NOTE: HAWSER FORCES COMPUTED FROM WATER-SURFACE MEASUREMENTS, BOTH LOCKS FILLED SIMULTANEUOSLY. COMPUTATIONS SIMULATE THE BOW OF THE BARGES LOCATED 181 FT FROM THE UPPER PINTLE

COMPUTED
LONGITUDINAL HAWSER FORCES
TYPE 1 DESIGN F&E SYSTEM
3 X 5 BARGE ARRANGEMENT
LOCATED IN UPPER APPROACH
TO LANDSIDE LOCK

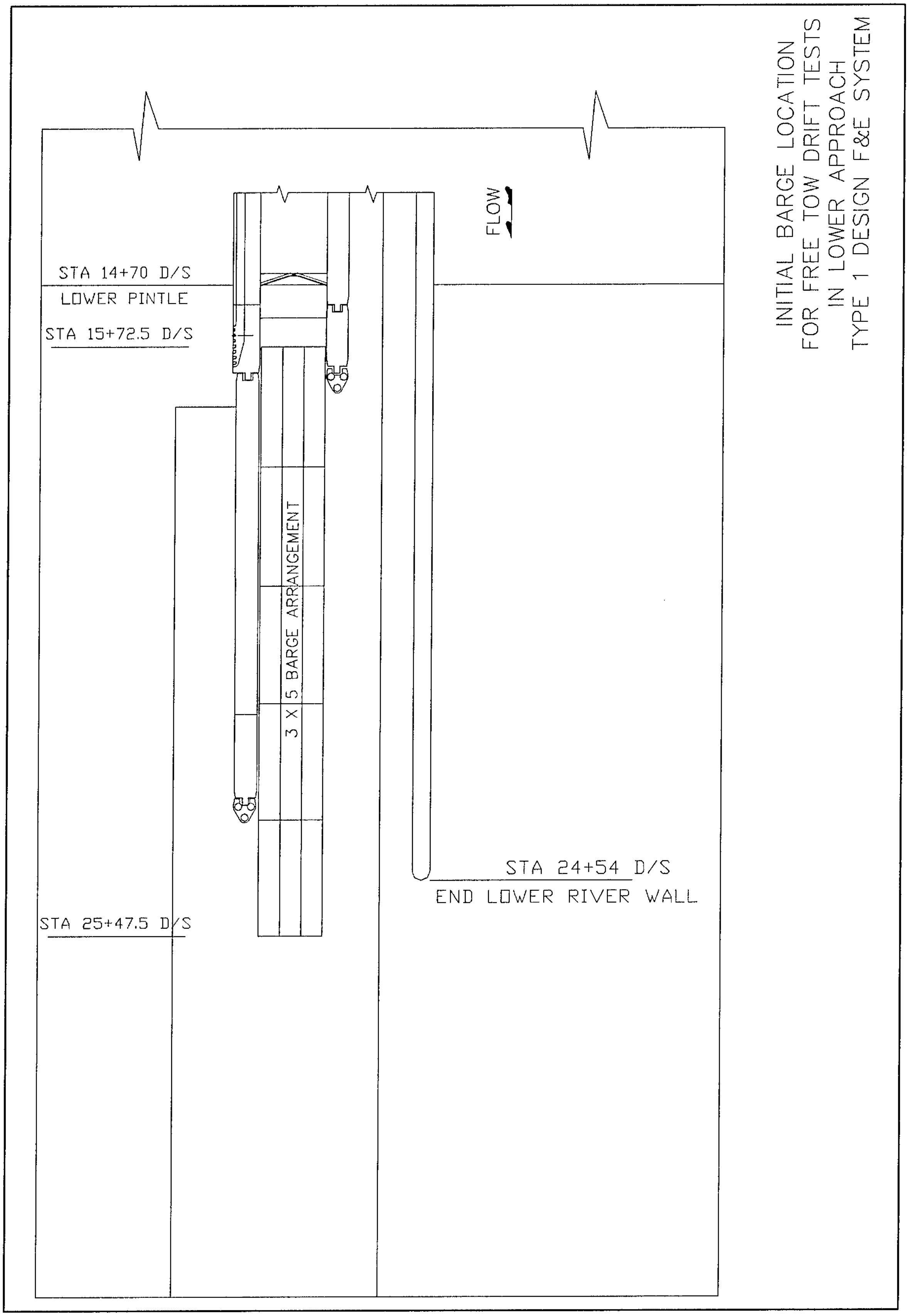
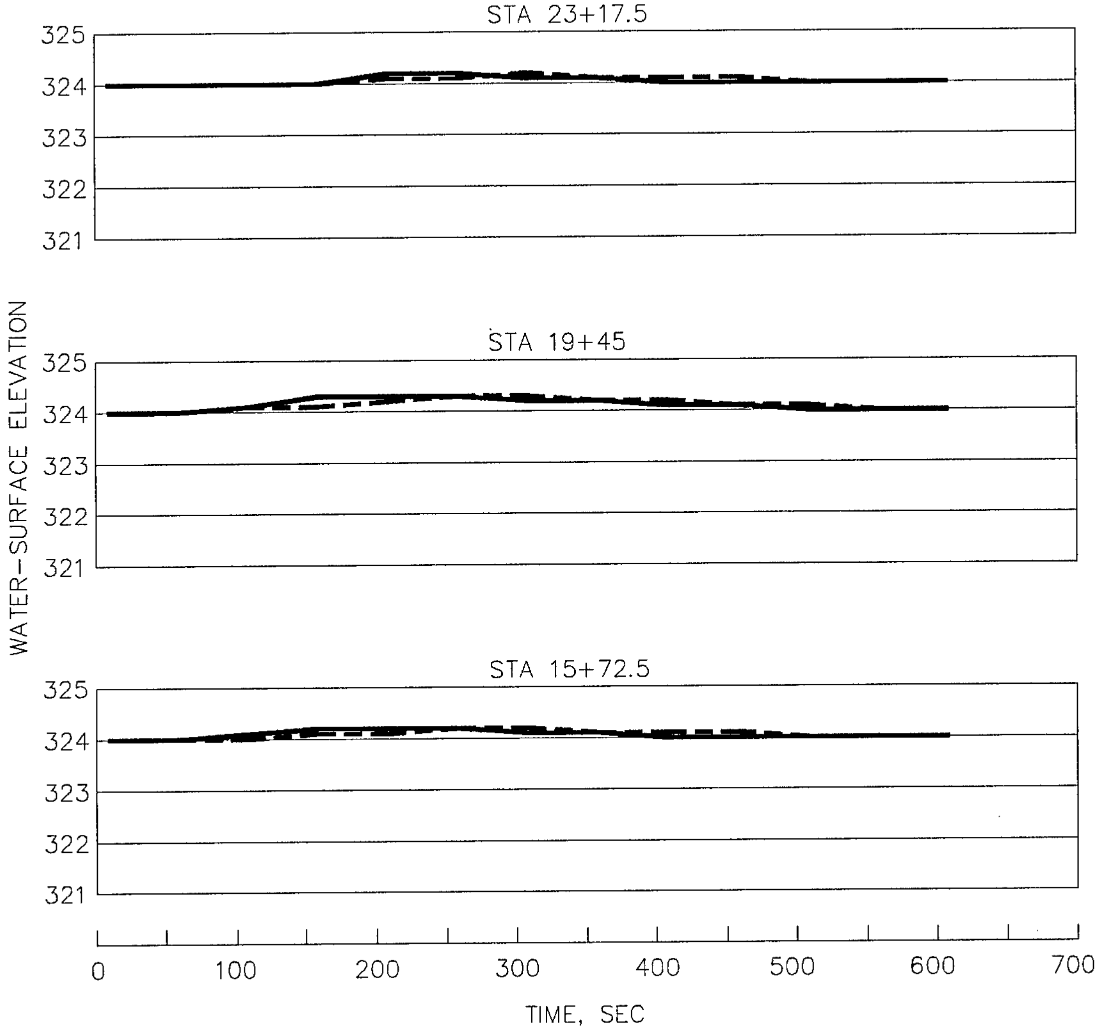

INITIAL BARGE LOCATION
FOR FREE TOW DRIFT TESTS
IN LOWER APPROACH
TYPE 1 DESIGN F&E SYSTEM
FLOW
STA 14+70 D/S
LOWER PINTLE
STA 15+72.5 D/S
3 X 5 BARGE ARRANGEMENT
STA 24+54 D/S
END LOWER RIVER WALL
STA 25+47.5 D/S

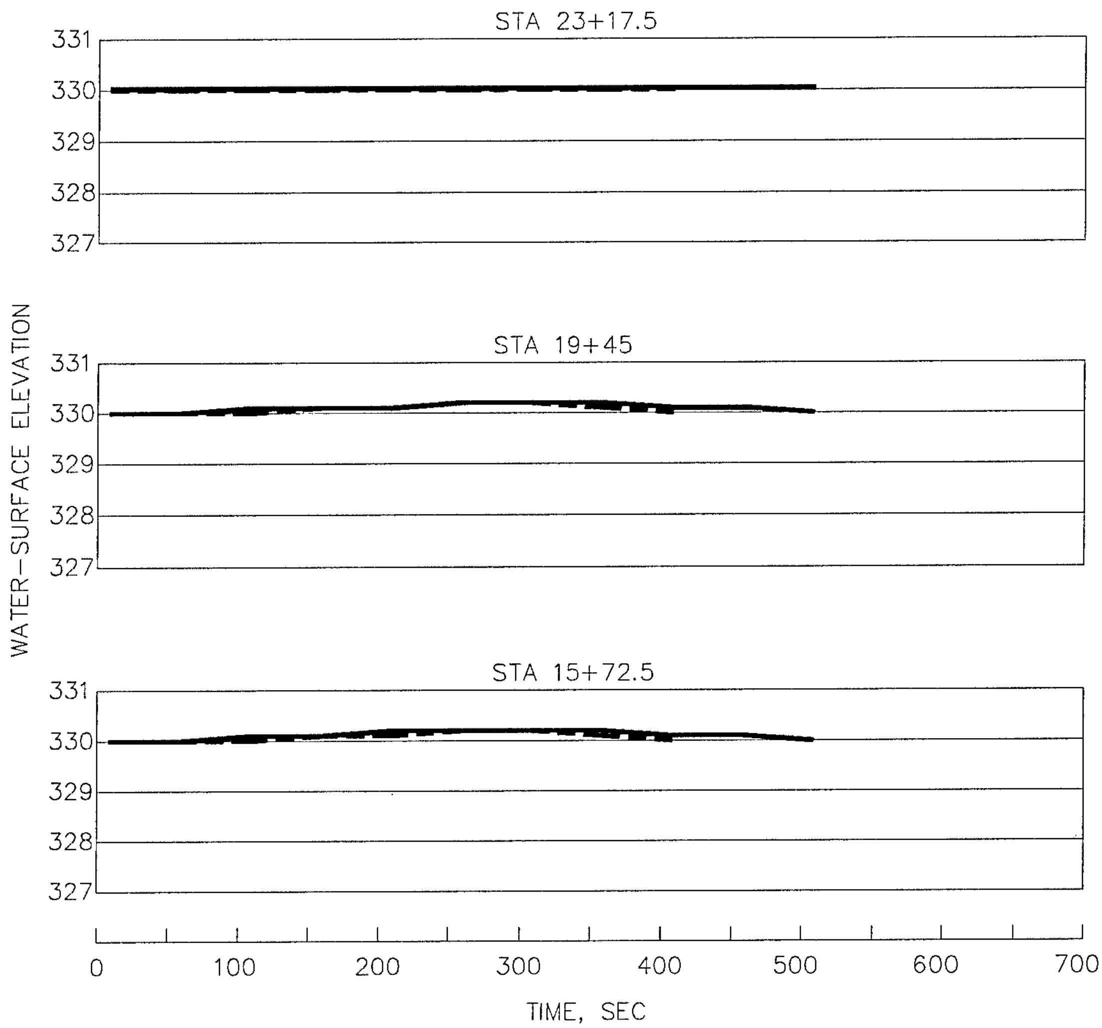
Plate 36



NOTE: WATER-SURFACE MEASURED 55 FT LANDWARD FROM RIVERSIDE APPROACH WALL OF LANDSIDE LOCK

——— 2 MIN EMPTY VALVES
- - - - 5 MIN EMPTY VALVES

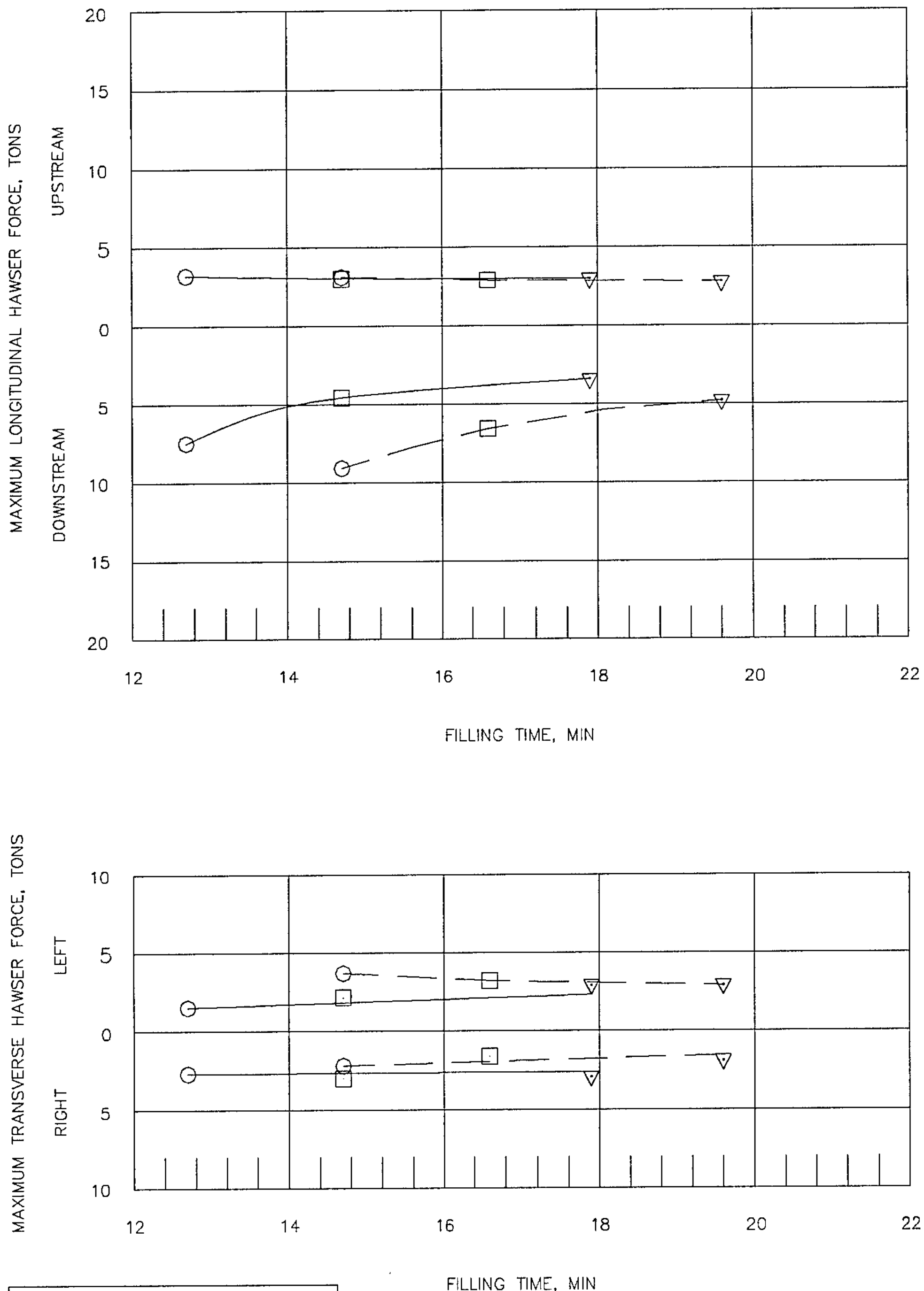
WATER-SURFACE ELEVATIONS
IN LOWER APPROACH
TYPE 1 DESIGN F&E SYSTEM
UPPER POOL EL 342.0
LOWER POOL EL 324.0



NOTE: WATER-SURFACE MEASURED 55 FT LANDWARD FROM RIVERSIDE APPROACH WALL OF LANDSIDE LOCK

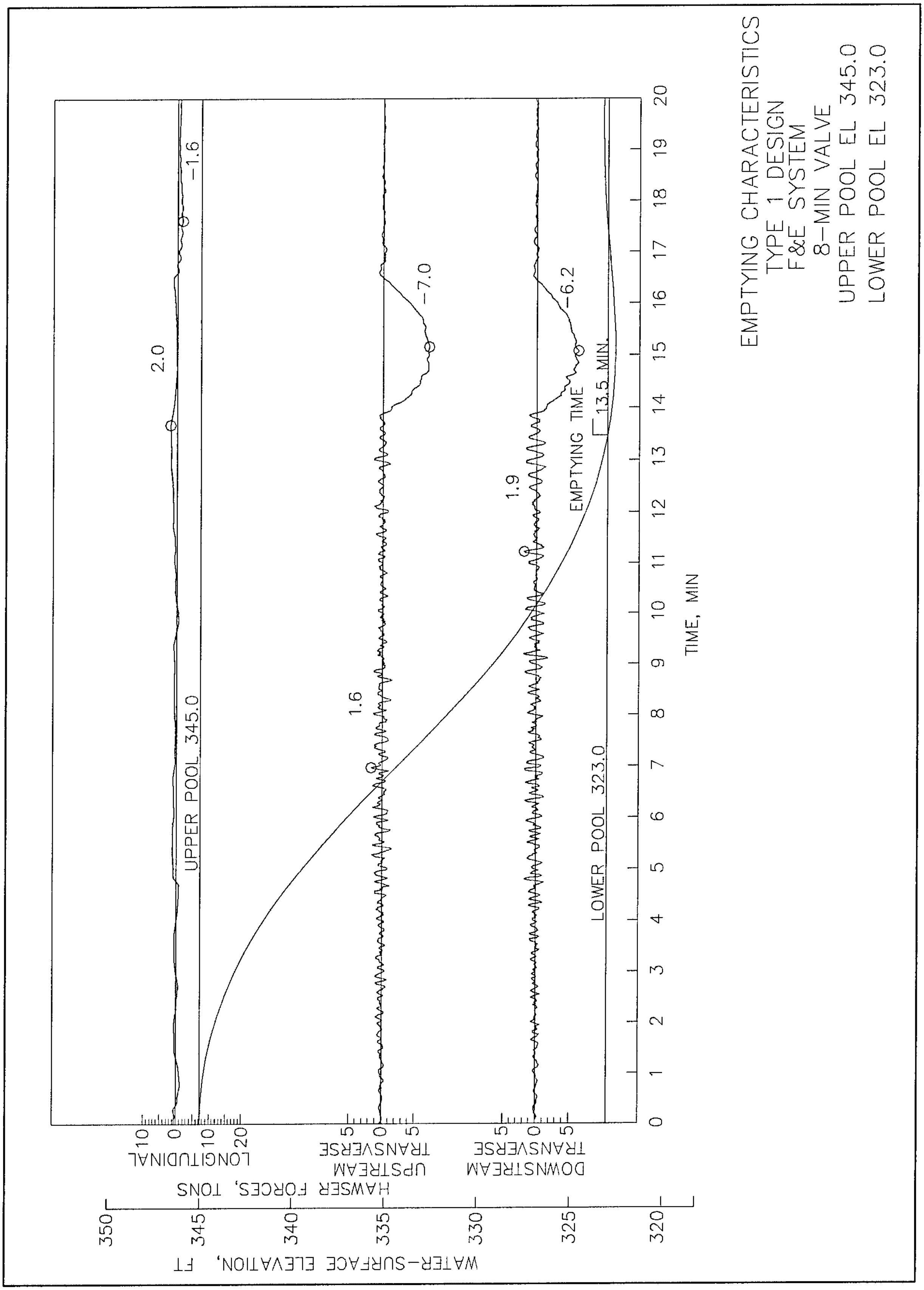
—— 2 MIN EMPTY VALVES
– – – 5 MIN EMPTY VALVES

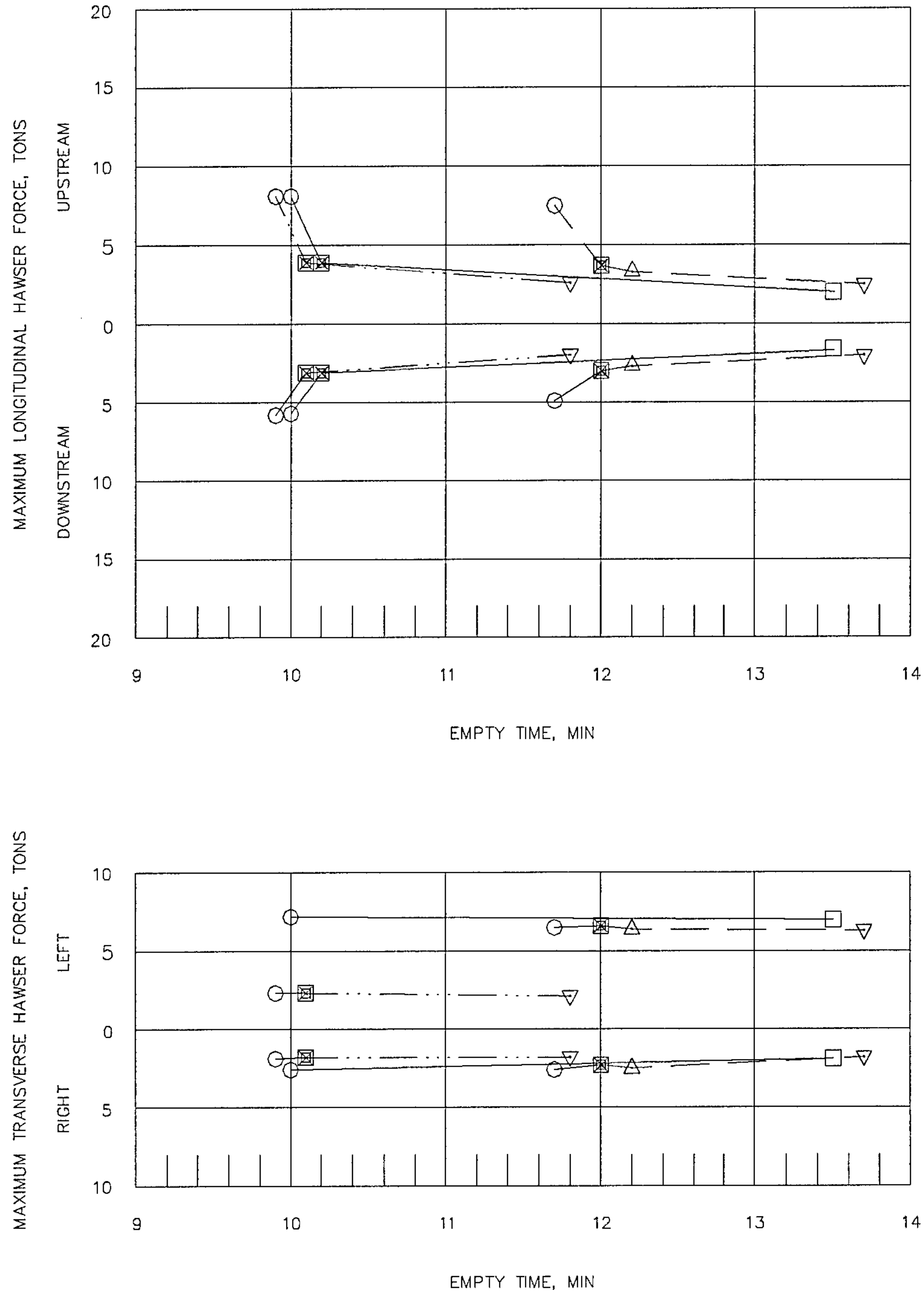
WATER-SURFACE ELEVATIONS
IN LOWER APPROACH
TYPE 1 DESIGN F&E SYSTEM
UPPER POOL EL 342.0
LOWER POOL EL 330.0



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
□	9
▽	15
———	22-FT LIFT
— —	30-FT LIFT

HAWSER FORCES
DURING FILLING
TYPE 1 DESIGN
F&E SYSTEM
LOWER POOL EL 323.0


EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
F&E SYSTEM
8-MIN VALVE
UPPER POOL EL 345.0
LOWER POOL EL 323.0
UPPER POOL 345.0
LOWER POOL 323.0
EMPTYING TIME
13.5 MIN.
2.0
-1.6
1.6
-7.0
1.9
-6.2
TIME, MIN
WATER-SURFACE ELEVATION, FT
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
⊠	1.5
△	2
▽	5
□	8
———	22-FT LIFT, LOWER POOL EL 323.0
— —	30-FT LIFT, LOWER POOL EL 323.0
— · · · —	22-FT LIFT, LOWER POOL EL 324.0

HAWSER FORCES
DURING EMPTYING
TYPE 1 DESIGN
F&E SYSTEM

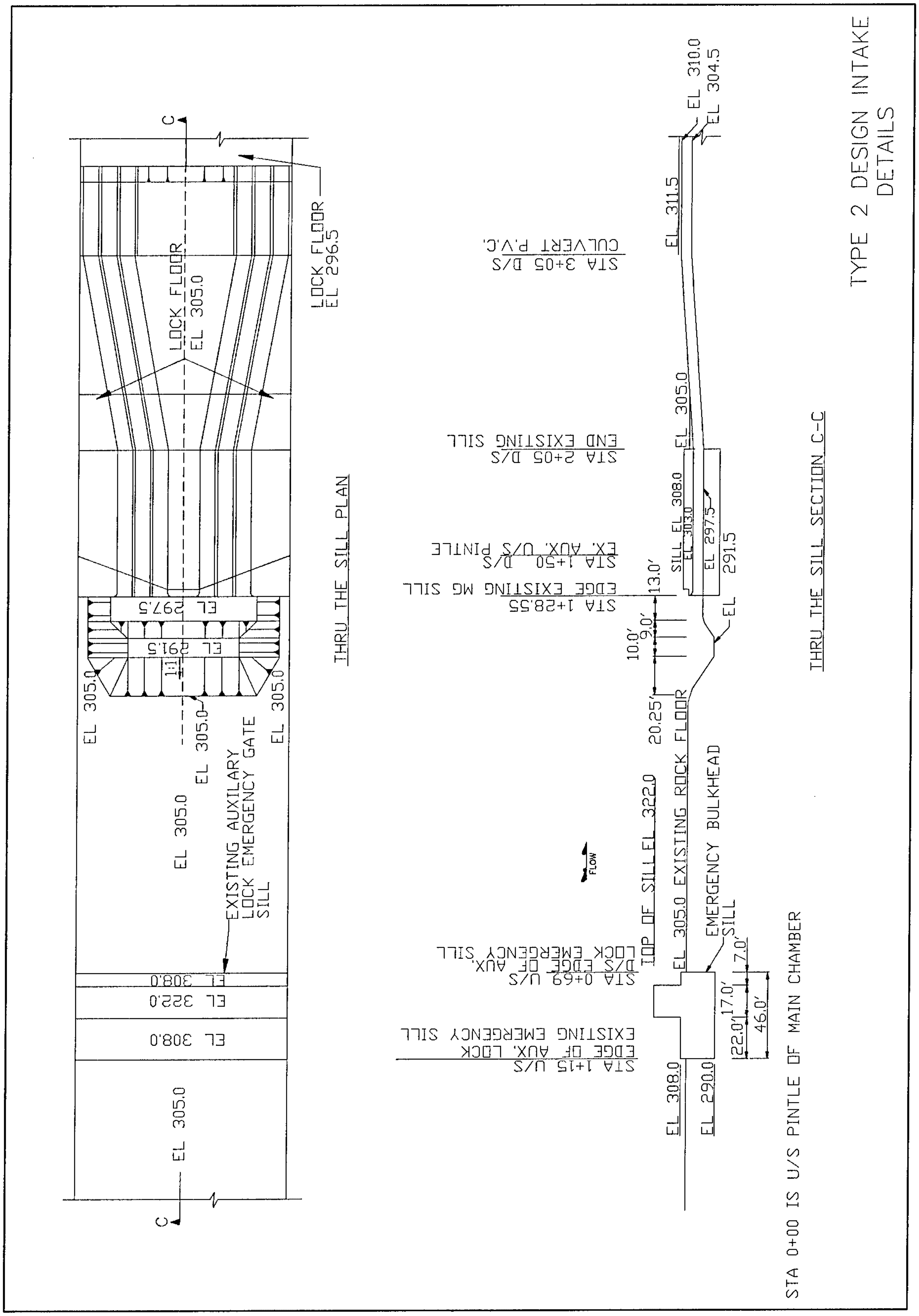
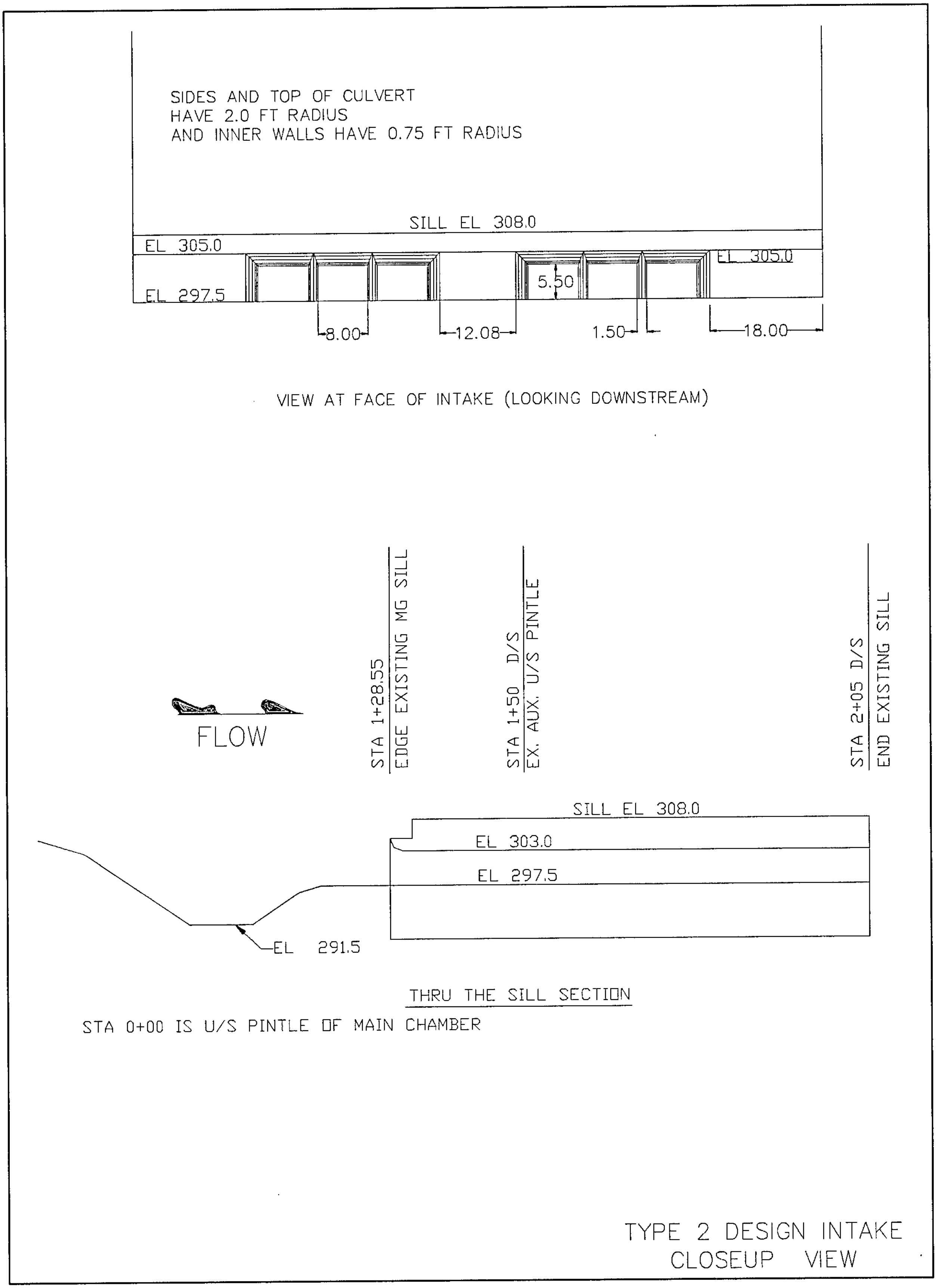
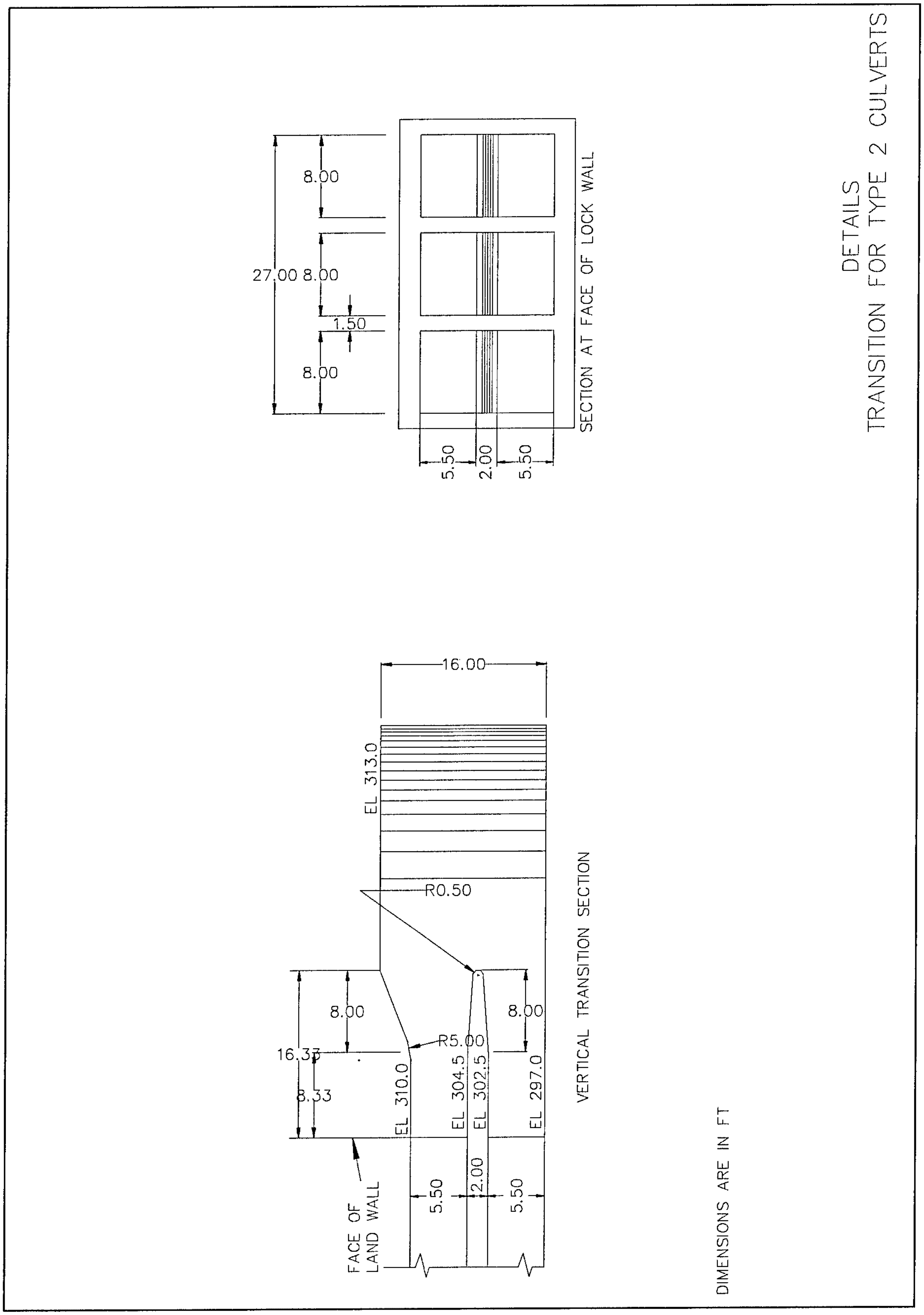

TYPE 2 DESIGN INTAKE DETAILS
THRU THE SILL PLAN
THRU THE SILL SECTION C-C
STA 0+00 IS U/S PINTLE OF MAIN CHAMBER
LOCK FLOOR EL 305.0
LOCK FLOOR EL 296.5
EL 297.5
EL 291.5
1:1
EL 305.0
EXISTING AUXILARY LOCK EMERGENCY GATE SILL
EL 308.0
EL 322.0
EL 308.0
EL 305.0
STA 3+05 D/S CULVERT P.V.C.
STA 2+05 D/S END EXISTING SILL
STA 1+50 D/S EX. AUX. U/S PINTLE
STA 1+28.55 EDGE EXISTING MG SILL
STA 0+69 U/S D/S EDGE OF AUX. LOCK EMERGENCY SILL
STA 1+15 U/S EDGE OF AUX. LOCK EXISTING EMERGENCY SILL
EL 310.0
EL 304.5
EL 311.5
EL 305.0
SILL EL 308.0
EL 303.0
EL 297.5
EL 291.5
EL
13.0'
9.0'
10.0'
20.25'
TOP OF SILL EL 322.0
EL 305.0 EXISTING ROCK FLOOR
EMERGENCY BULKHEAD
EMERGENCY SILL
FLOW
7.0'
17.0'
46.0'
22.0'
EL 308.0
EL 290.0
C
C

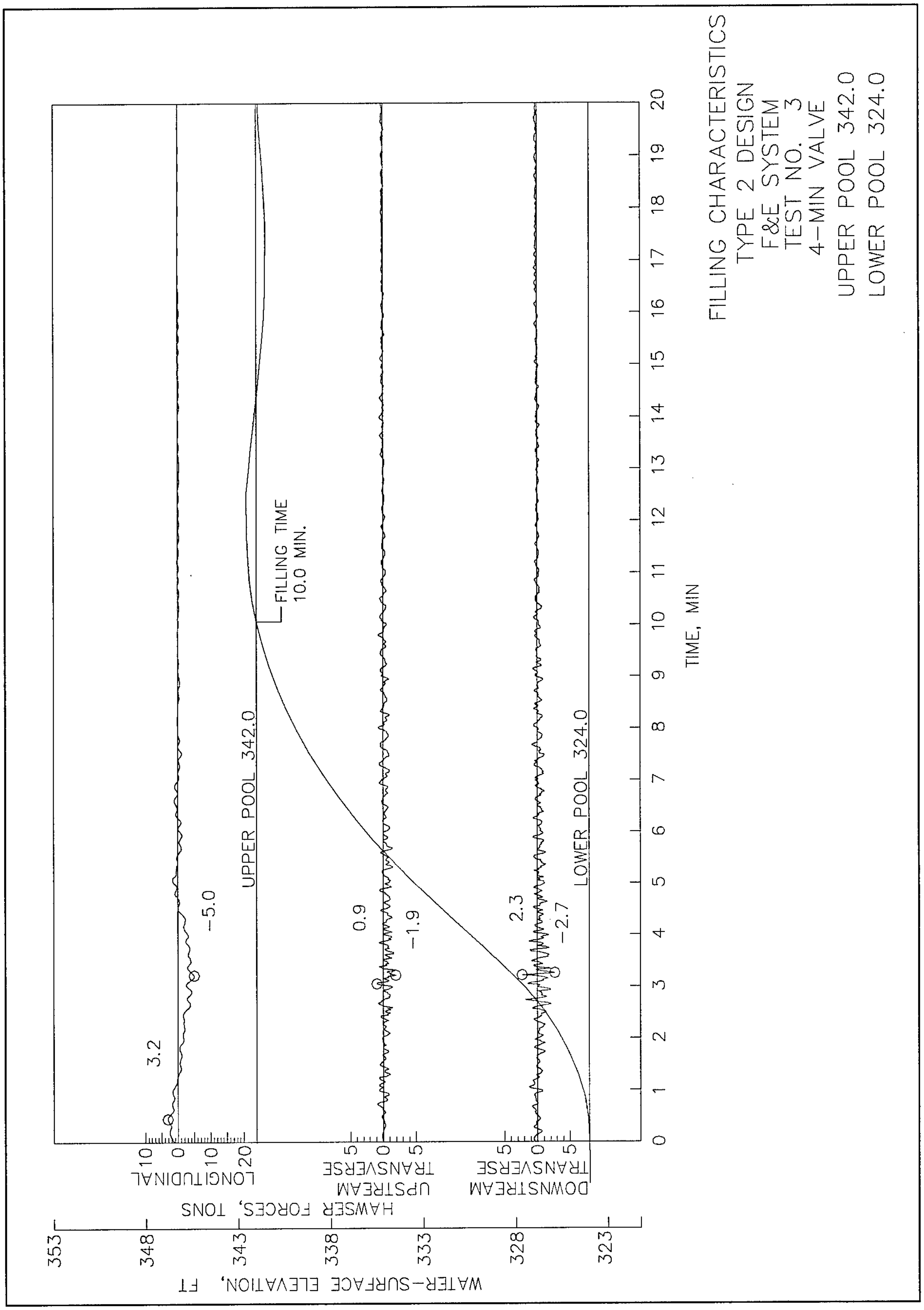
Plate 42



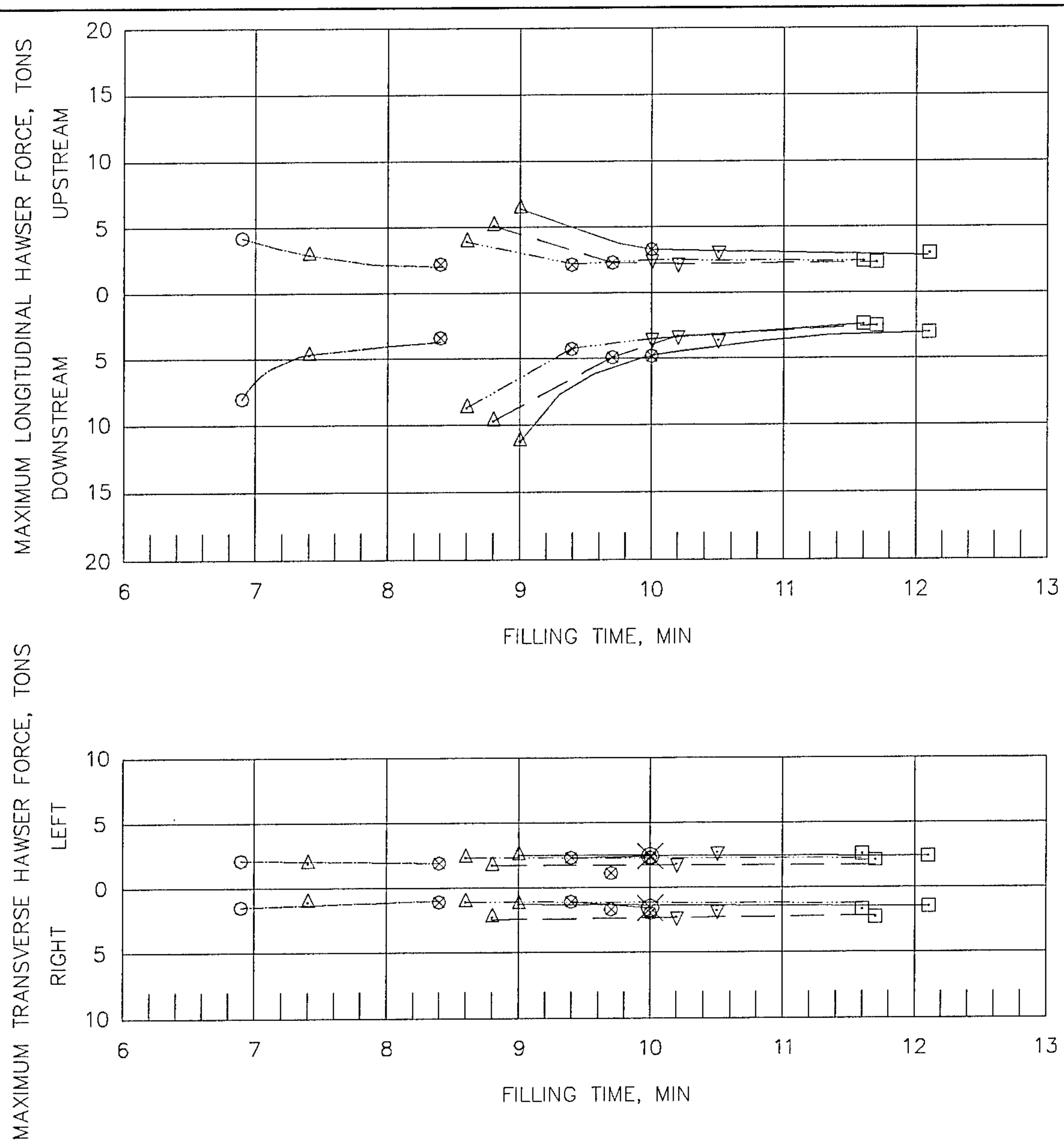
SIDES AND TOP OF CULVERT
HAVE 2.0 FT RADIUS
AND INNER WALLS HAVE 0.75 FT RADIUS
SILL EL 308.0
EL 305.0
EL 305.0
EL 297.5
5.50
8.00
12.08
1.50
18.00
VIEW AT FACE OF INTAKE (LOOKING DOWNSTREAM)
FLOW
STA 1+28.55
EDGE EXISTING MG SILL
STA 1+50 D/S
EX. AUX. U/S PINTLE
STA 2+05 D/S
END EXISTING SILL
SILL EL 308.0
EL 303.0
EL 297.5
EL 291.5
THRU THE SILL SECTION
STA 0+00 IS U/S PINTLE OF MAIN CHAMBER
TYPE 2 DESIGN INTAKE
CLOSEUP VIEW



DETAILS
TRANSITION FOR TYPE 2 CULVERTS

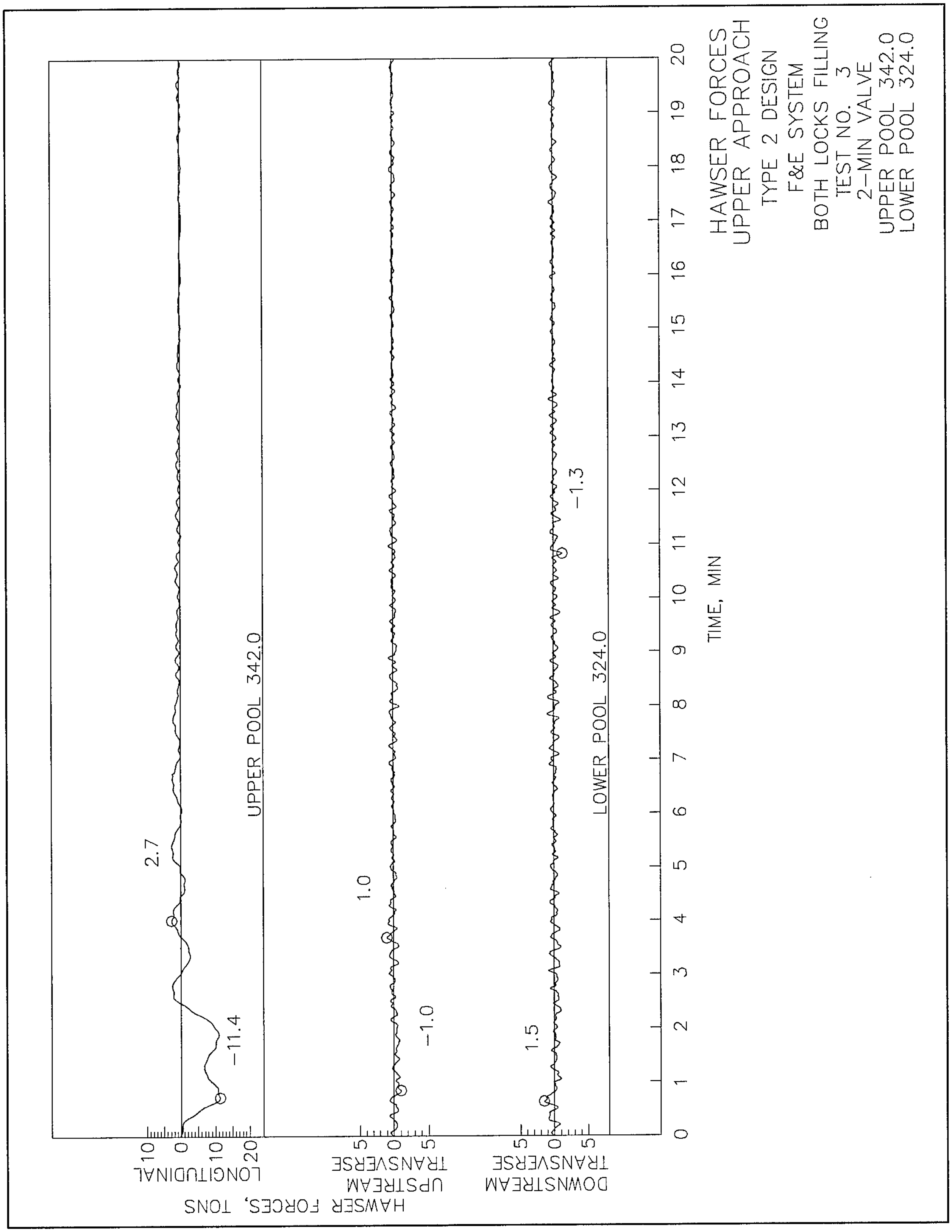


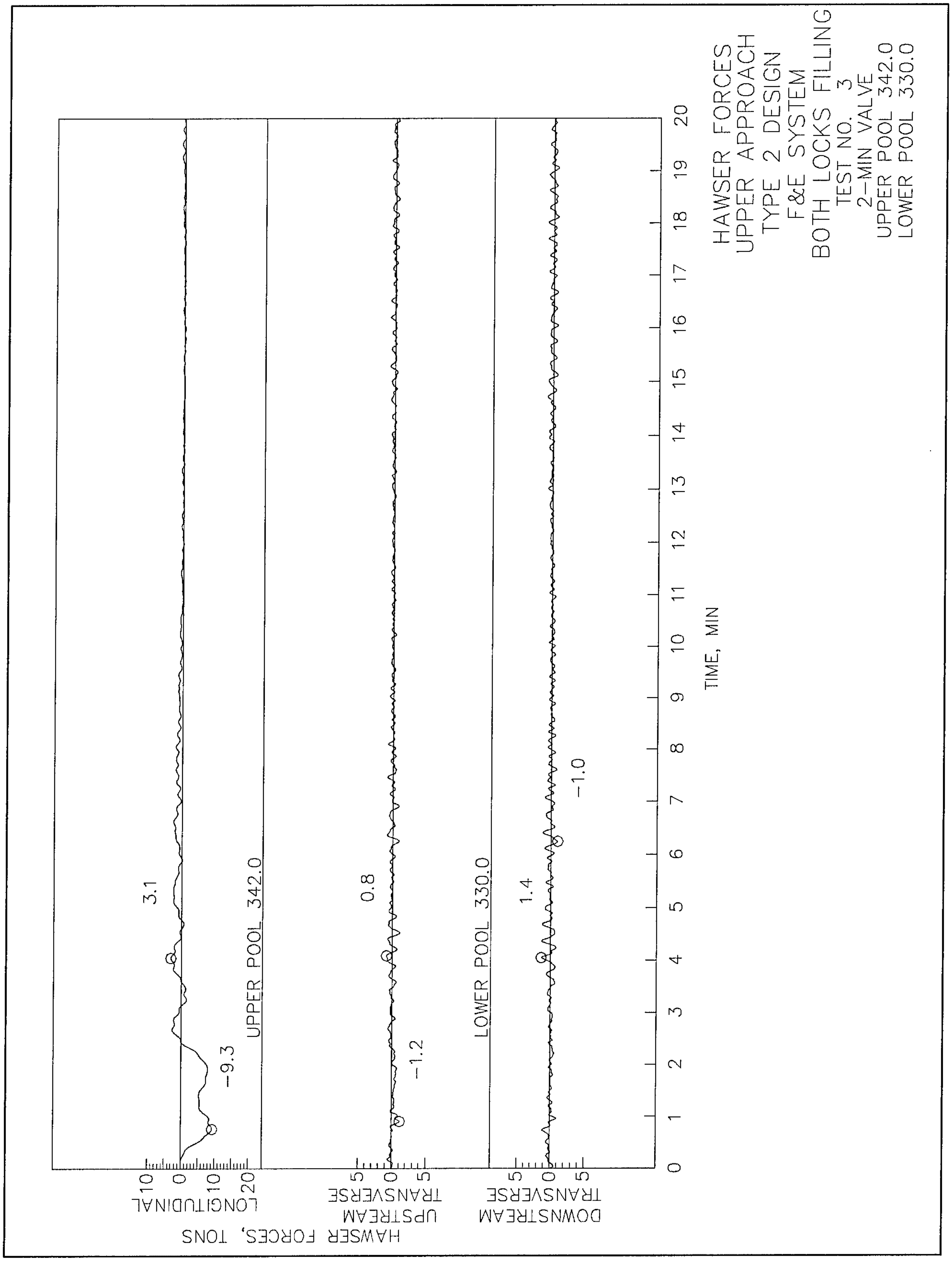
FILLING CHARACTERISTICS
TYPE 2 DESIGN
F&E SYSTEM
TEST NO. 3
4-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
WATER-SURFACE ELEVATION, FT
353
348
343
338
333
328
323
HAWSER FORCES, TONS
LONGITUDINAL
10 0 10 20
UPSTREAM TRANSVERSE
5 0 5
DOWNSTREAM TRANSVERSE
5 0 5
TIME, MIN
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
3.2
-5.0
0.9
-1.9
2.3
-2.7
UPPER POOL 342.0
LOWER POOL 324.0
FILLING TIME
10.0 MIN.

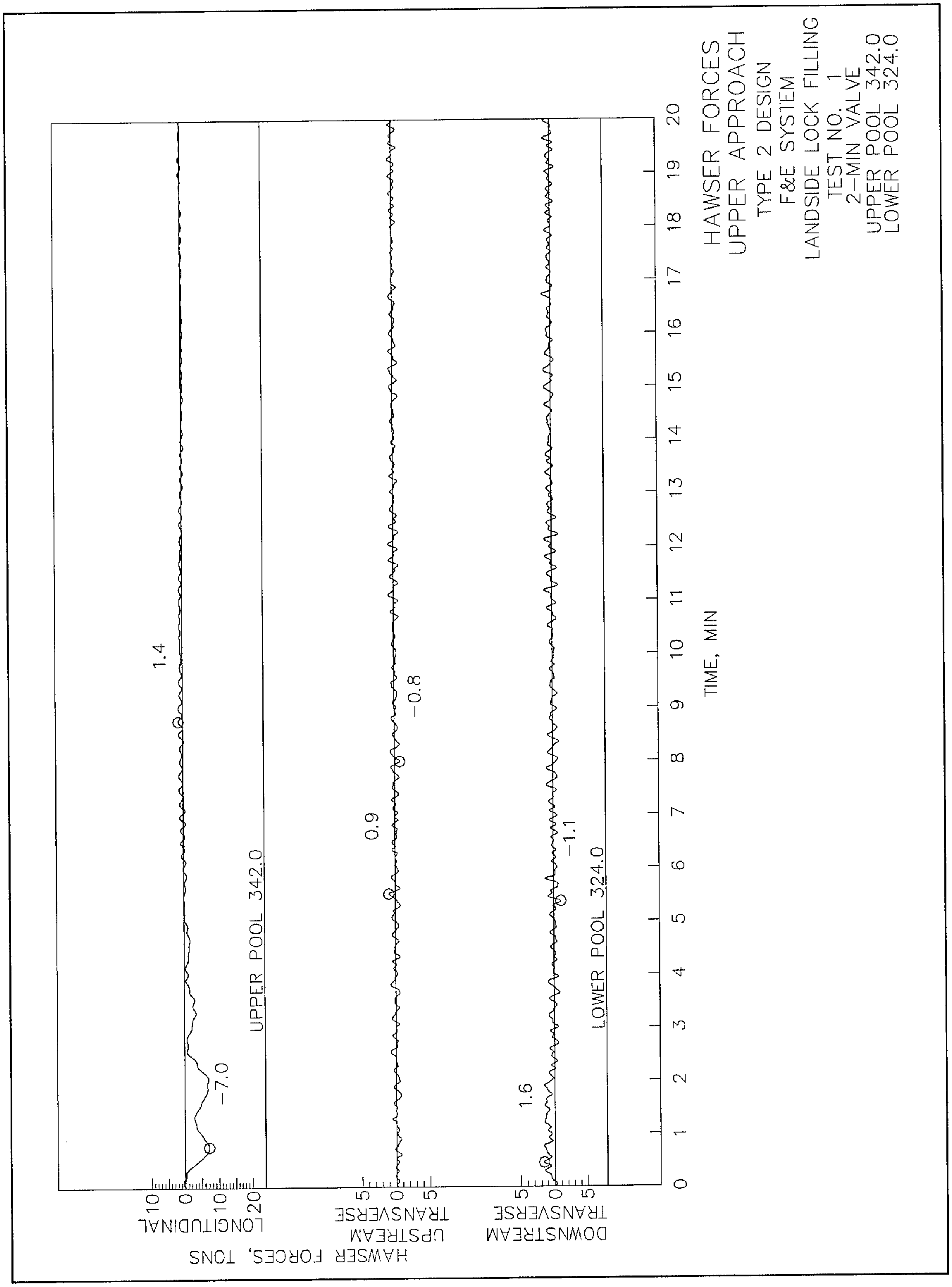


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
⊗	4
▽	5
⊡	8
————	18-FT LIFT, U. P. EL 342 AND L. P. EL 324
— —	17-FT LIFT, U. P. EL 342 AND L. P. EL 325
—···—	16-FT LIFT, U. P. EL 342 AND L. P. EL 326
—·—·—	12-FT LIFT, U. P. EL 342 AND L. P. EL 330

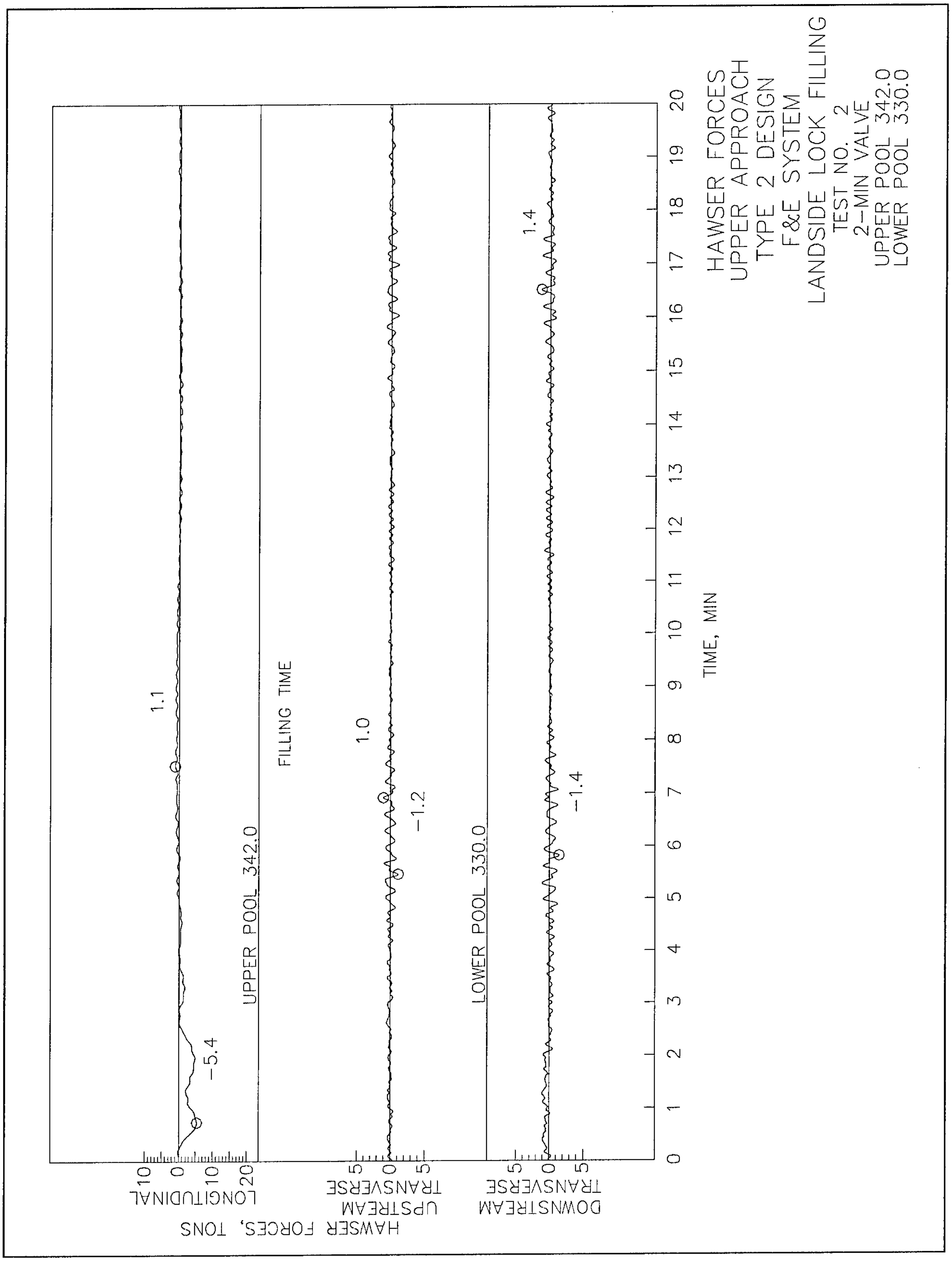
HAWSER FORCES
DURING FILLING
TYPE 2 DESIGN F&E SYSTEM


HAWSER FORCES
UPPER APPROACH
TYPE 2 DESIGN
F&E SYSTEM
BOTH LOCKS FILLING
TEST NO. 3
2-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
TIME, MIN
UPPER POOL 342.0
LOWER POOL 324.0
2.7
-11.4
1.0
-1.0
1.5
-1.3

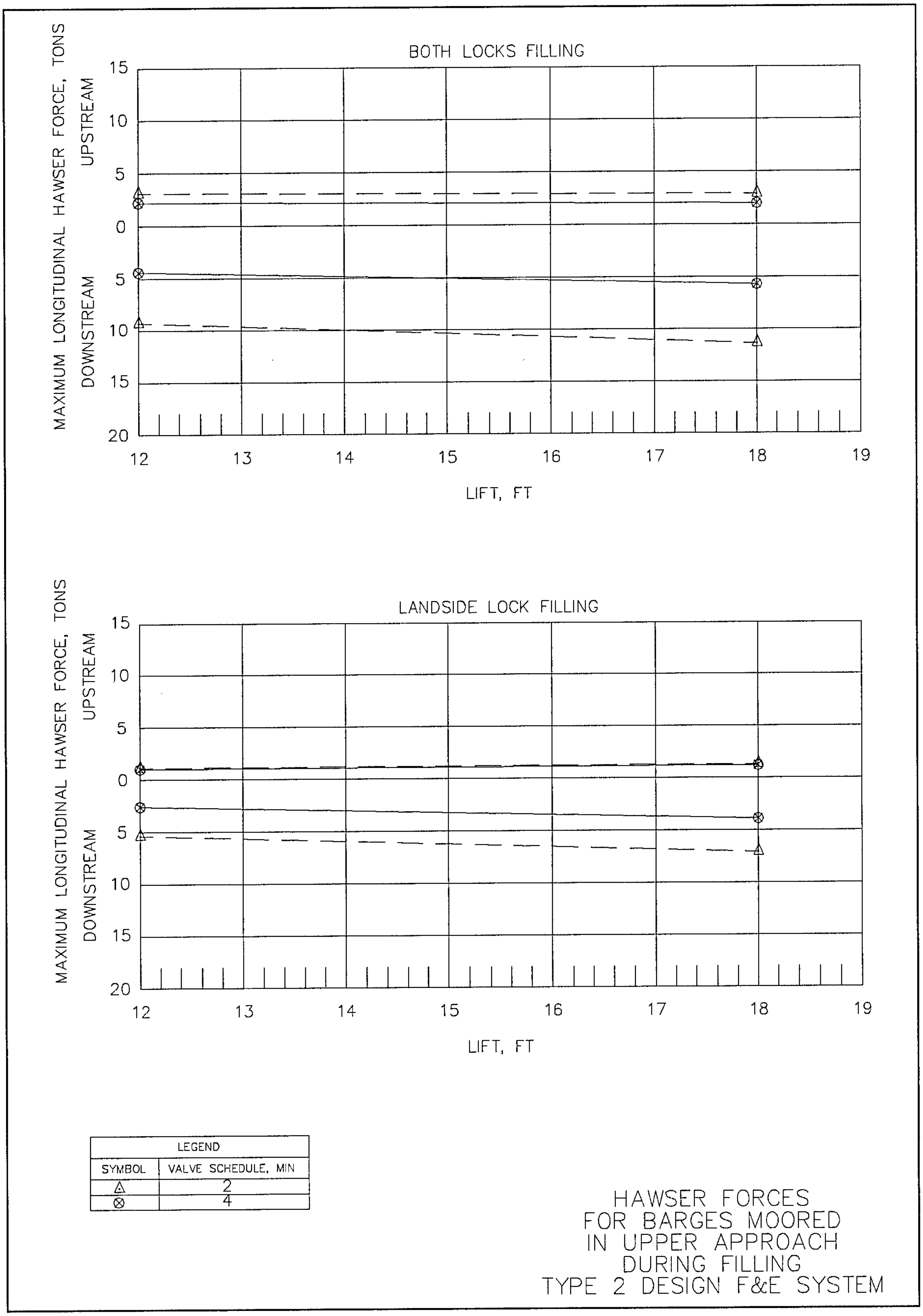

HAWSER FORCES
UPPER APPROACH
TYPE 2 DESIGN
F&E SYSTEM
BOTH LOCKS FILLING
TEST NO. 3
2-MIN VALVE
UPPER POOL 342.0
LOWER POOL 330.0
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
TIME, MIN
UPPER POOL 342.0
LOWER POOL 330.0
3.1
-9.3
0.8
-1.2
1.4
-1.0
-10 0 10 20
-5 0 5
-5 0 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

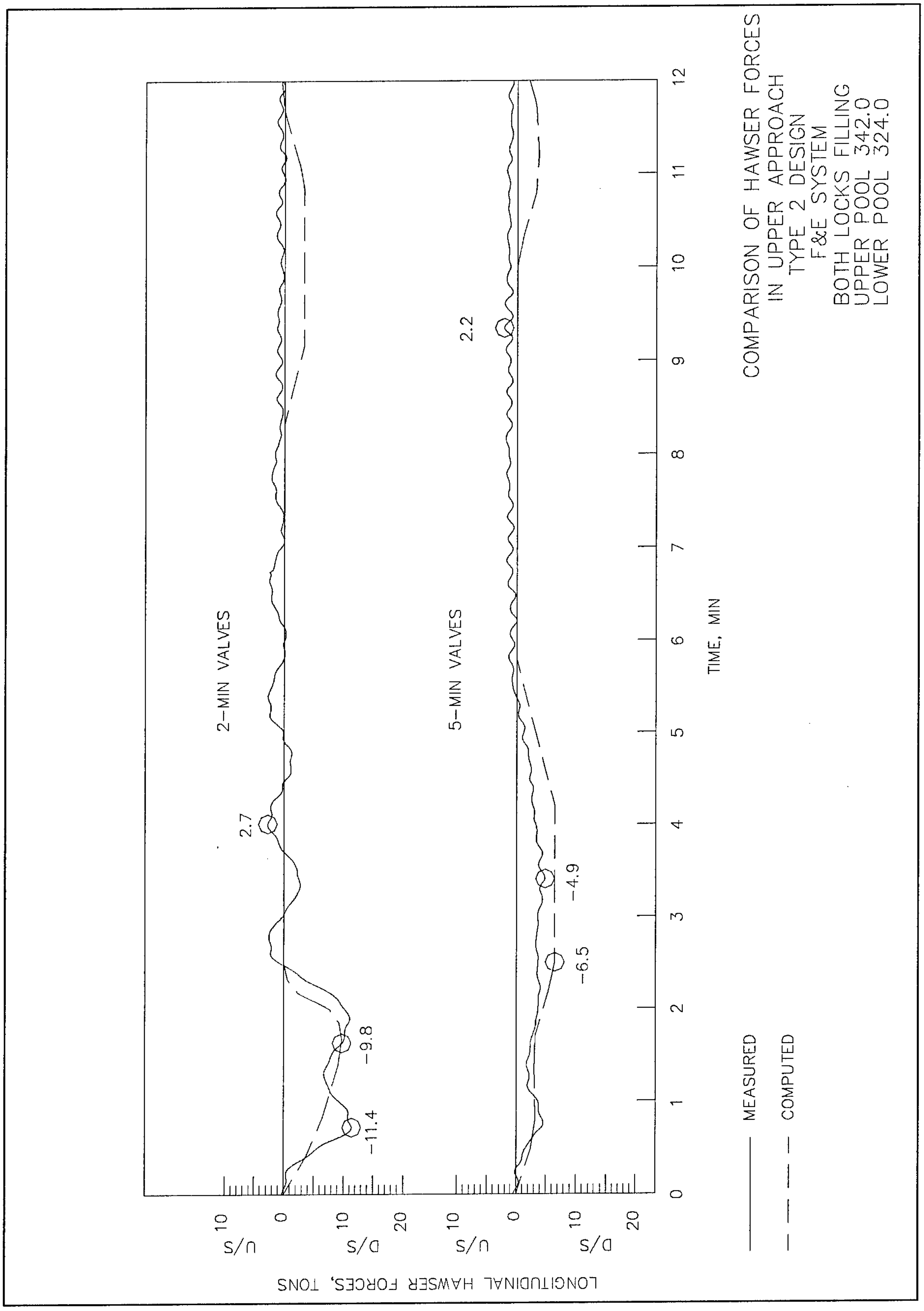


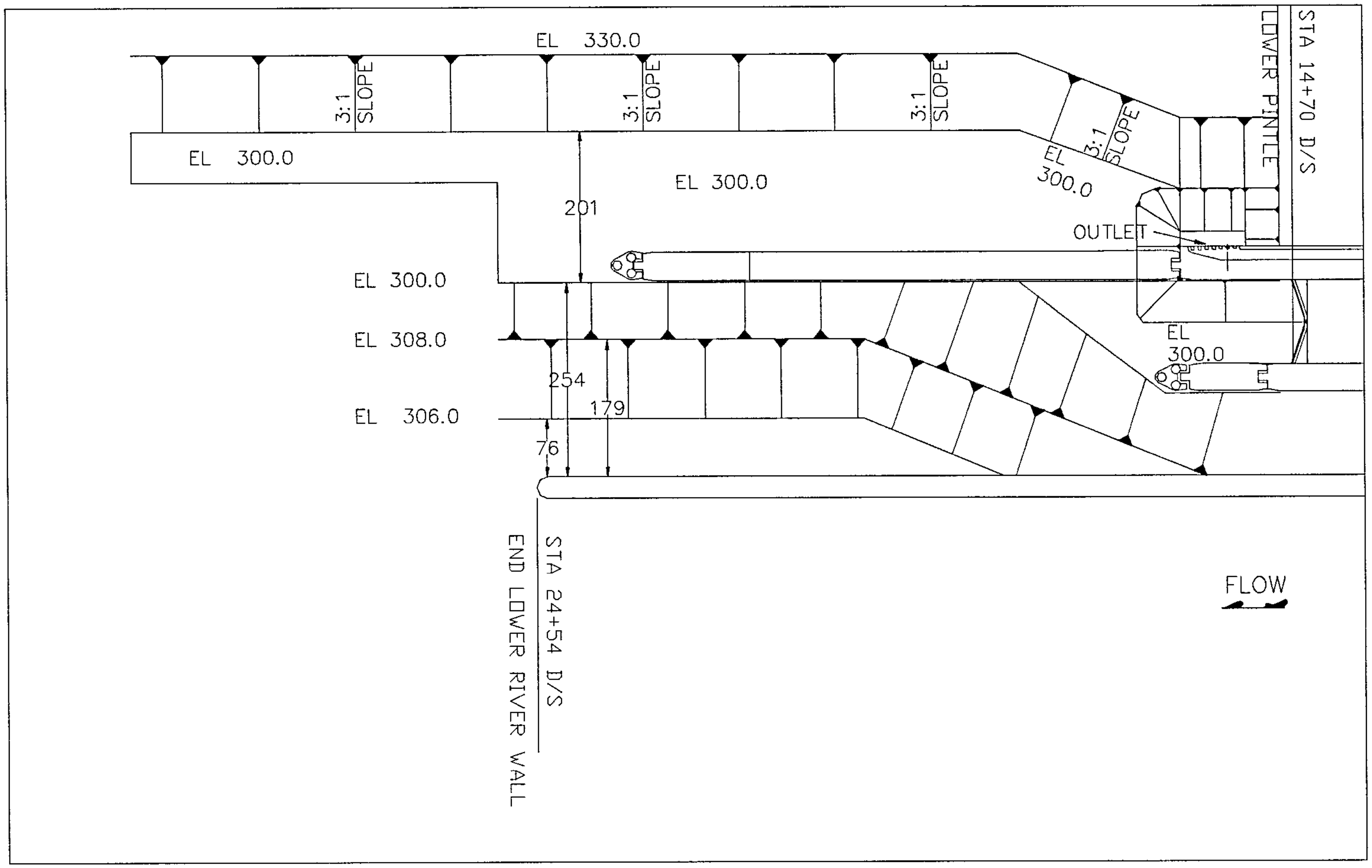
HAWSER FORCES
UPPER APPROACH
TYPE 2 DESIGN
F&E SYSTEM
LANDSIDE LOCK FILLING
TEST NO. 1
2-MIN VALVE
UPPER POOL 342.0
LOWER POOL 324.0
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
TIME, MIN
UPPER POOL 342.0
LOWER POOL 324.0
-7.0
1.4
0.9
-0.8
1.6
-1.1
10 0 10 20
5 0 5
5 0 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20



HAWSER FORCES
UPPER APPROACH
TYPE 2 DESIGN
F&E SYSTEM
LANDSIDE LOCK FILLING
TEST NO. 2
2-MIN VALVE
UPPER POOL 342.0
LOWER POOL 330.0
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM TRANSVERSE
DOWNSTREAM TRANSVERSE
TIME, MIN
UPPER POOL 342.0
LOWER POOL 330.0
FILLING TIME
-5.4
1.1
1.0
-1.2
-1.4
1.4
10
0
10
20
5
0
5
5
0
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

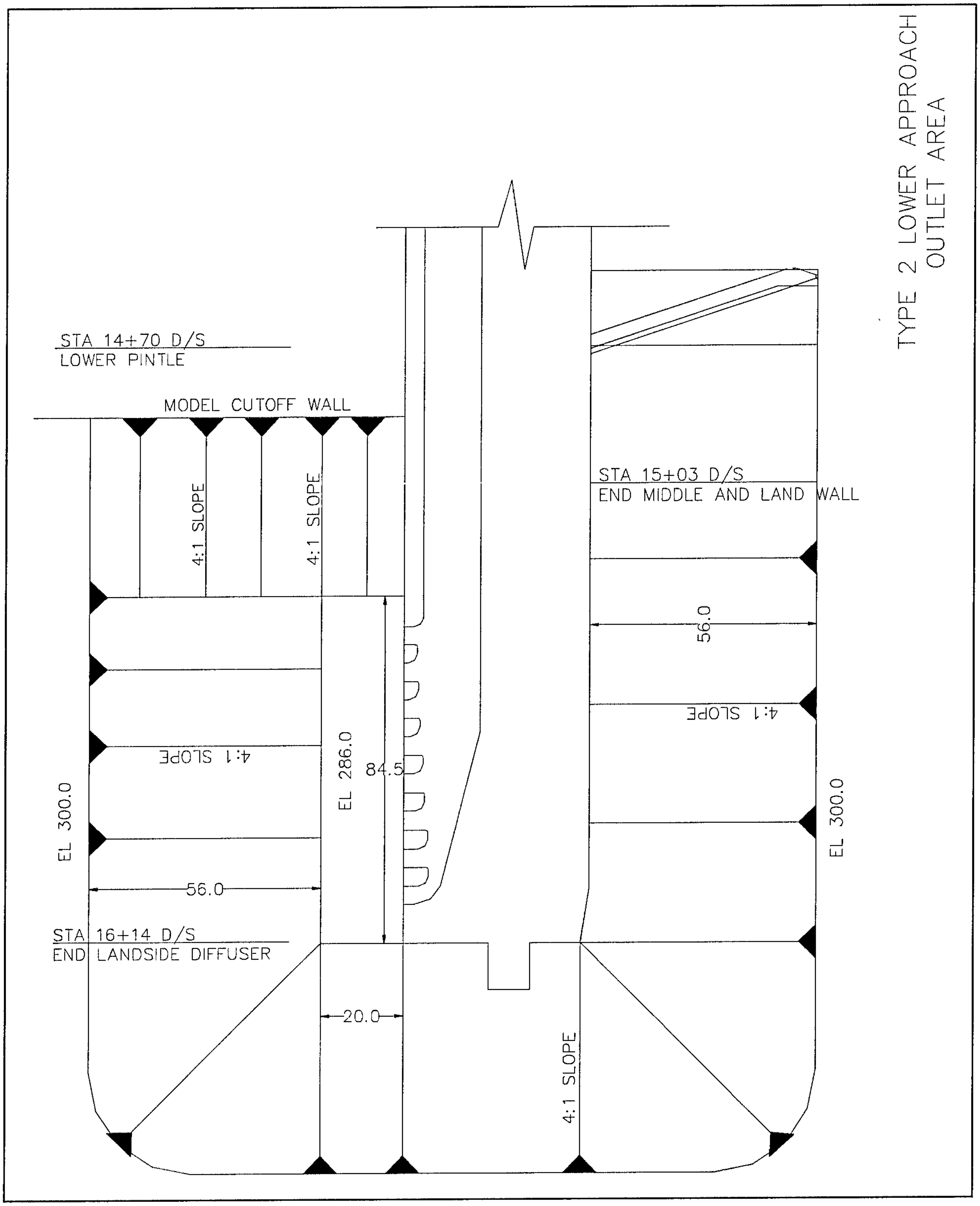

BOTH LOCKS FILLING
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
15
10
5
0
5
10
15
20
12
13
14
15
16
17
18
19
LIFT, FT
LANDSIDE LOCK FILLING
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
15
10
5
0
5
10
15
20
12
13
14
15
16
17
18
19
LIFT, FT
LEGEND
SYMBOL
VALVE SCHEDULE, MIN
△ 2
⊗ 4
HAWSER FORCES
FOR BARGES MOORED
IN UPPER APPROACH
DURING FILLING
TYPE 2 DESIGN F&E SYSTEM


COMPARISON OF HAWSER FORCES
IN UPPER APPROACH
TYPE 2 DESIGN
F&E SYSTEM
BOTH LOCKS FILLING
UPPER POOL 342.0
LOWER POOL 324.0
2-MIN VALVES
5-MIN VALVES
-11.4
-9.8
2.7
-6.5
-4.9
2.2
MEASURED
COMPUTED
LONGITUDINAL HAWSER FORCES, TONS
U/S
D/S
10
0
10
20
TIME, MIN
0
1
2
3
4
5
6
7
8
9
10
11
12



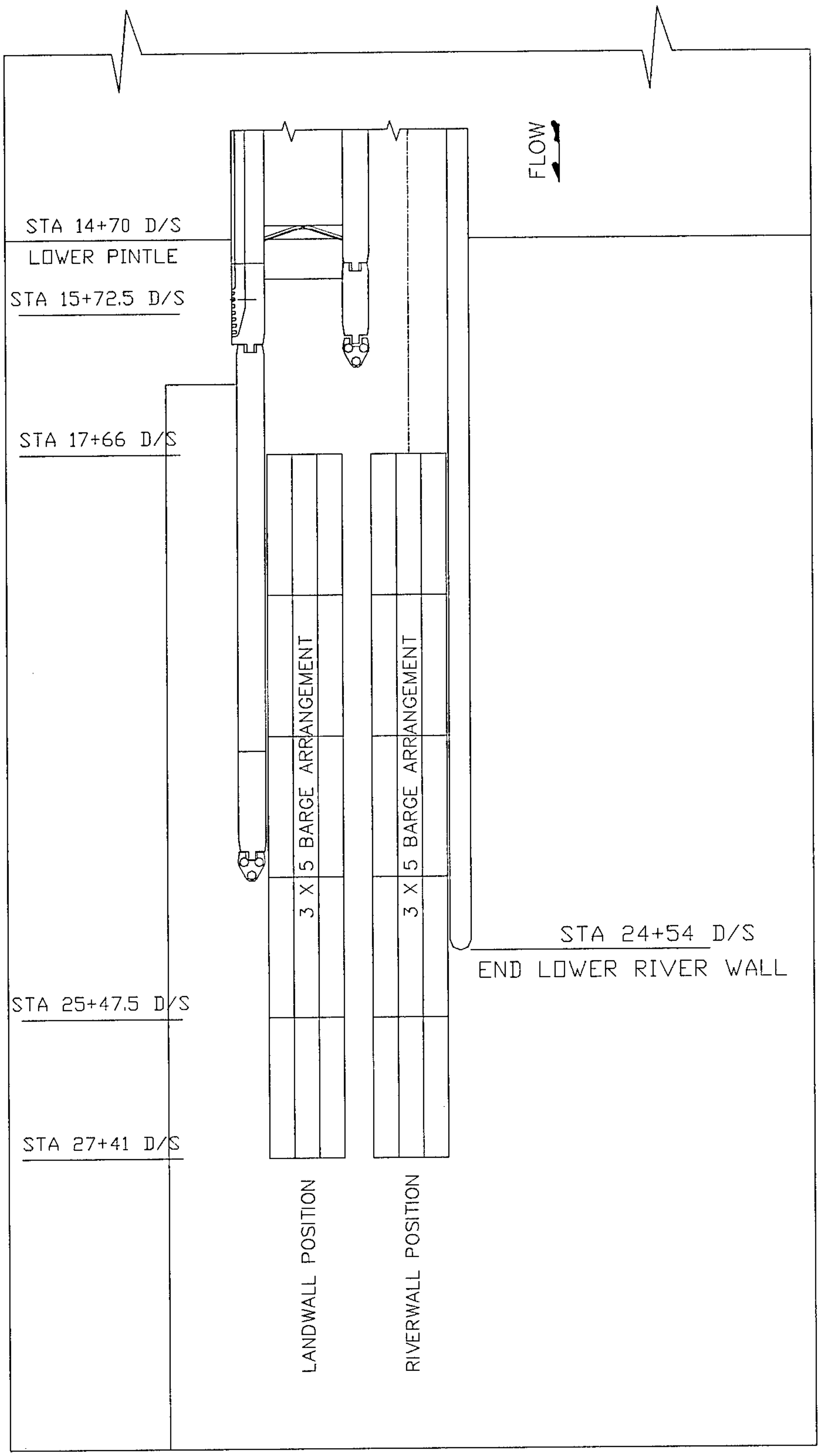
Dimensions are in ft

TYPE 2
LOWER APPROACH
TOPOGRAPHY

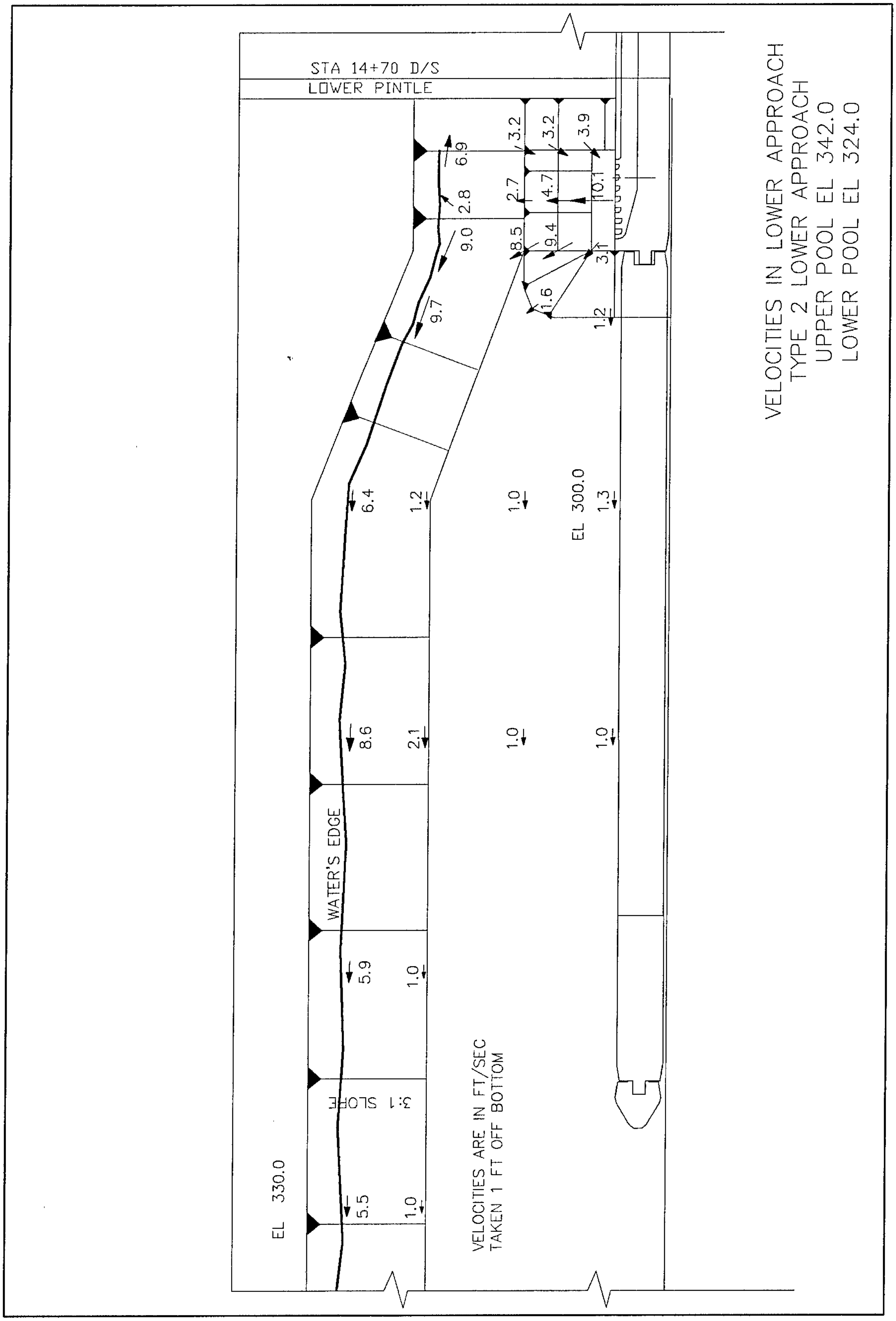


TYPE 2 LOWER APPROACH
OUTLET AREA
STA 14+70 D/S
LOWER PINTLE
MODEL CUTOFF WALL
4:1 SLOPE
4:1 SLOPE
STA 15+03 D/S
END MIDDLE AND LAND WALL
56.0
4:1 SLOPE
4:1 SLOPE
EL 286.0
84.5
EL 300.0
EL 300.0
56.0
STA 16+14 D/S
END LANDSIDE DIFFUSER
20.0
4:1 SLOPE

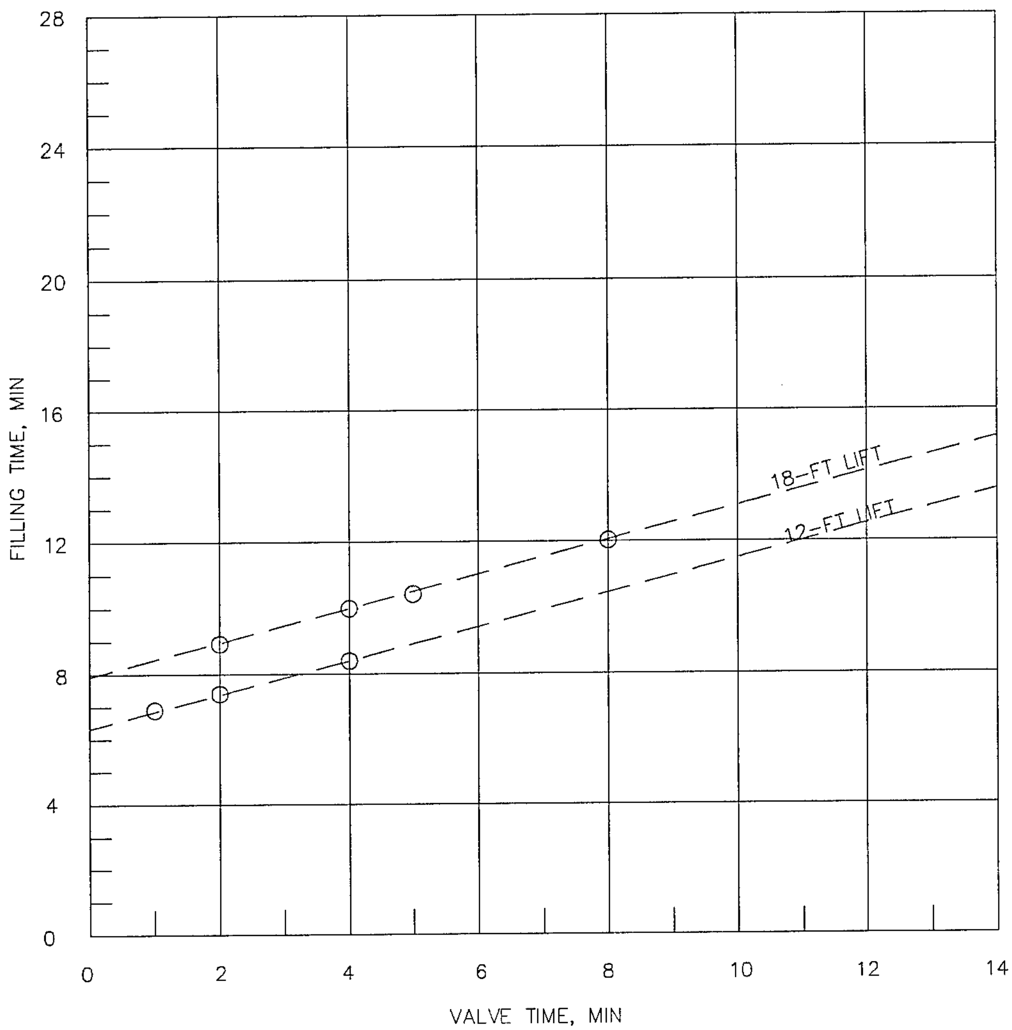
Plate 54



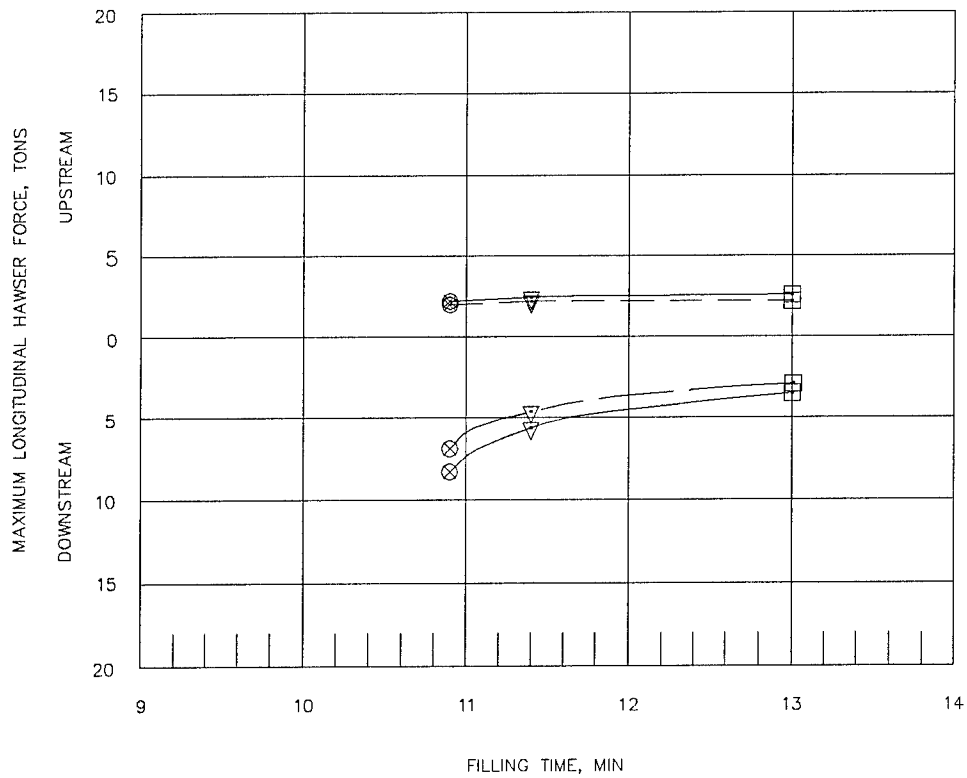
INITIAL BARGE LOCATIONS
FOR FREE TOW DRIFT TESTS
IN LOWER APPROACH
TYPE 2 LOWER APPROACH

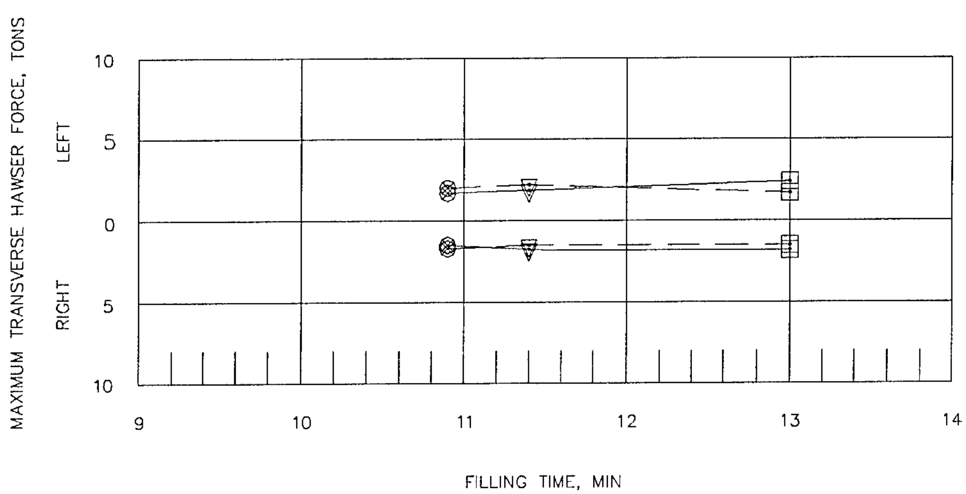


VELOCITIES IN LOWER APPROACH
TYPE 2 LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
STA 14+70 D/S
LOWER PINTLE
WATER'S EDGE
3:1 SLOPE
EL 330.0
EL 300.0
VELOCITIES ARE IN FT/SEC
TAKEN 1 FT OFF BOTTOM
3.2
3.2
3.9
6.9
2.8
2.7
4.7
10.1
9.0
8.5
9.4
3.1
9.7
1.6
1.2
6.4
1.2
1.0
1.3
8.6
2.1
1.0
1.0
5.9
1.0
5.5
1.0



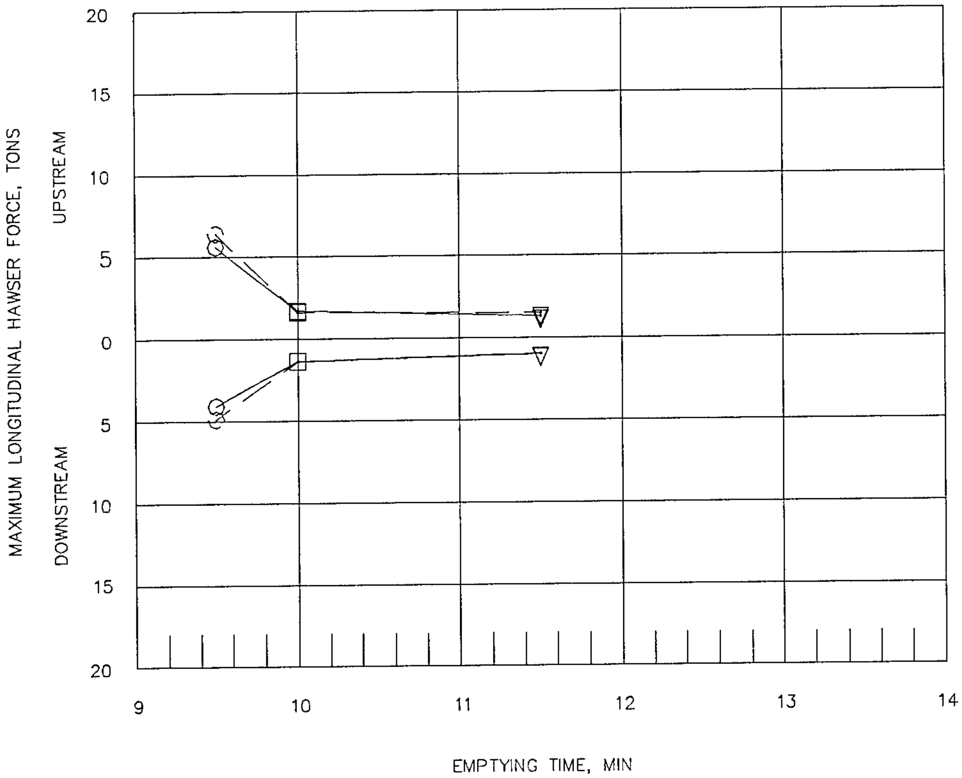
OPERATION TIMES FOR
FILLING
TYPE 2 DESIGN F&E SYSTEM
18-FT LIFT
UPPER POOL EL 342.0
LOWER POOL EL 324.0

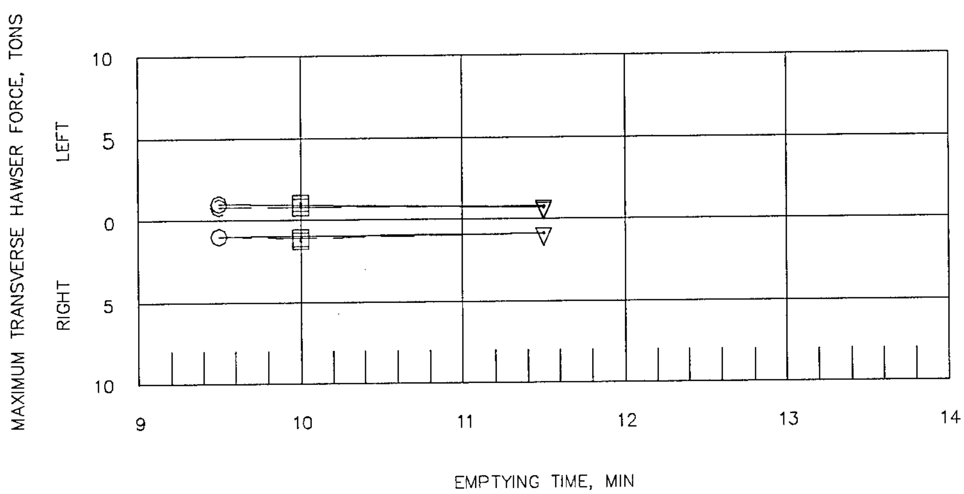




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
⊗	4
▽	5
⊡	8
LINETYPE	CENTER OF BARGES
———	STA 8+10
— —	STA 8+40.5

HAWSER FORCES
DURING FILLING
TYPE 2 DESIGN F&E SYSTEM
CHAMBER EXTENDED 50 FT
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
⊡	2
▽	5
LINETYPE	CENTER OF BARGES
————	STA 8+10
—— ——	STA 8+40.5

HAWSER FORCES
DURING EMPTYING
TYPE 2 DESIGN F&E SYSTEM
EXTENDED AUX. LOCK
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT